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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 832
Contribution from the Bureau of Public Roads.
THOS. H. MACDONALD, Chief

Washington, D. C. PROFESSIONAL PAPER June 7, 1920

# THE FLOW OF WATER IN DREDGED DRAINAGE DITCHES

## THE RESULTS OF EXPERIMENTS TO DETERMINE THE ROUGHNESS COEFFICIENT, *n*, IN KUTTER'S FORMULA

By

**C. E. RAMSER, Senior Drainage Engineer**

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## INTRODUCTION.

Kutter's formula is generally accepted by engineers as being the most satisfactory formula in use for computing the flow of water in open channels. After a thorough and unbiased study of all known formulas for computing the flow in open channels, engineers of the Miami Conservancy District conclude that "Although the Kutter formula is not ideal it is the best equation available at the present time."[1] The results obtained by the use of this formula are, however, affected to such a degree by the coefficient of roughness, *n*, that the selection of the correct value for this factor is a matter of the highest importance. The series of experiments described and summarized in the following pages were made for the purpose of determining just what values of *n* properly apply to the various conditions of channel, and the endeavor has been made to present this information in the form that will be of the most practical value to engineers charged with the design of drainage channels or the computation of the discharge capacity of existing channels.

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[1] The Maimi Conservancy District, Technical Reports, Part IV. "Calculation of Flow in Open Channels," by Ivan E. Houk, Assoc. M. Am. Soc. C. E.

The term *n* in Kutter's formula is a measure of all the conditions in a channel that tend to retard the flow. It is quite often regarded as simply a measure of the friction between the flowing water and the material forming the perimeter, all other conditions in the channel being disregarded. Some of the conditions that influence the value of *n* for earth channels are irregularities in the wetted perimeter, nonuniformity of cross section in size and shape, the growth of vegetation in the channel, such as grass, weeds, roots, vines, bushes and trees, and the presence of other obstructions to flow, such as logs, stumps, drift, and débris of all kinds. Various combinations of these conditions that may exist in a channel make it difficult to choose the proper value of *n* in computing the flow of an open channel or the probable flow for proposed artificial channels. The engineer who has had a wide personal observation of conditions in channels for which values of *n* have been determined is generally well qualified to choose the proper values of *n* in the design of channels. On the other hand, the engineer who has not had similar experience must depend for his choice of *n* upon views and descriptions of channels for which values of *n* have been determined by experiment. In this paper views and careful descriptions of the channels for which values of *n* were determined are presented as being the best method of making the results of practical application.

The experiments described were conducted in six different localities, namely, Lee County, Miss.; Bolivar County, Miss.; western Tennessee; western Iowa; southern North Carolina; and eastern Florida. The first four sets of experiments were made by the author. The experiments conducted in North Carolina and Florida were made by A. D. Morehouse and F. E. Staebner, respectively, both drainage engineers of the Bureau of Public Roads. All of these experiments were conducted under the direction of S. H. McCrory, chief of drainage investigations.

## FIELD MEASUREMENTS.

### DISCHARGE.

Particular care was taken to secure accurate discharge measurements. With few exceptions the gauging stations were located on single span bridges, so that there was no interference with the natural flow of the water. Where suitable existing bridges at desirable sections could not be found, suspension footbridges were constructed, one of which is shown in Plate I, figure 1. A cable gauging station was built on the Bogue Phalia channel in Bolivar County, Miss. (See Plate I, fig. 2.) Where the cable stations and suspension bridges were built ideal gauging sections were obtained.

Velocity measurements were made with a small Price current meter. These measurements were made at intervals of 2½ feet across the streams for the smallest channels, 5 feet for the medium-sized channels, and 10 feet for the largest channels. At the measuring points the velocity was determined at the surface, mid-depth, and the bottom of the stream. In a few instances the velocity was measured at 0.2 and 0.8 depths. The best methods were observed in the use and care of the current meter, and it is believed that the results are entirely dependable.

Carefully made soundings were obtained during low water stages at the velocity-measuring points and wherever a decided change in the perimeter of the channel took place. As a check on these measurements, and to detect any changes due to silting or erosion, soundings were also made at the time of the velocity measurements. The depths were measured to the nearest tenth of a foot.

### SLOPE OF WATER SURFACE.

The slope of the water surface was measured along the straightest and most uniform course of channel available near the gauging station, except in two instances where it was desired to ascertain the values of *n* for curved and crooked channels. The courses chosen were such that no tributary streams entered the channel and no decidedly abrupt changes in the bottom grade of the channel occurred along the courses, and were so located as to exclude such obstructions as logs, fallen trees, piling, and bridge piers. In one experiment, however, courses were chosen with a view to determining the influence of such obstructions upon the flow in the channels. Where the course of the channel was not limited in length by the conditions named above, the length of the course was made at least 10 times the top width of the channel. It was apparent that representative values of *n* could not be obtained for a channel if a long course was chosen without regard to the conditions mentioned above. For instance, during a high stage in the Bogue Hasty channel, in Bolivar County, Miss., drift accumulated at a pile trestle bridge just above the slope course, causing a fall of 0.3 foot from the upstream to the downstream side of the bridge. The actual slope of the water surface for this channel was less than 1 foot per mile, from which it is apparent that had a long slope course been chosen which included this bridge, decidedly different values of *n* would have been obtained. Also where long slope courses are used, incorrect values of *n* are often obtained, due to the entrance of surface water along the course.

In these experiments the slope of the water surface was determined by making vertical measurements from permanently set reference points to the surface of the water. These reference points were established on horizontal arms extending from vertical posts set firmly in the ground at each end of the course. Variations in water level of from 3 to 4 feet could be measured from each post, and a sufficient number of posts were set on the side slope of the channel so that all fluctuations in water surface could be measured. The elevations of the points on the arms of the posts were determined with a level to the nearest two or three thousandths of a foot and were carefully checked after every high stage in the stream to detect any possible changes due to the disturbance of the posts. The posts, however, were set in such a substantial manner, that very seldom were any changes found. The vertical measurements from the points on the arms to the water surface were made with a hook-gauge measuring rod. In some instances a stilling box arrangement was employed in connection with the hook gauge. These measurements were made either before or after the gauging was made, and often both before and after. They were made simultaneously by observers at either end of the course, or by one observer who first read at the end of the course nearer the gauging station, then at the other end, and then repeated the first measurement, the average of the first and third measurements being used. This method is based upon the assumption that the same time elapses between the first and second measurements as between the second and third measurements; hence errors due to a rising or falling stage are practically eliminated. Realizing that the accuracy of the results depended largely upon a correct determination of the slope, the utmost care was taken to secure accurate and dependable slope measurements.

### CROSS SECTIONS.

The length of the slope course was carefully measured along one bank of the stream and stakes were placed at intervals of 50 or 100 feet to mark the points where the cross sections were to be taken. Where the channel was regular the cross sections were taken at intervals of 100 feet. Where the channel was irregular they were taken 50 feet apart, or at such irregular intervals as to represent as nearly as possible the true average cross section of the course. In making the cross-sectional measurements, distances across the channel were measured from the stakes to the nearest tenth of a foot. For the smaller channels, where wading was possible, elevations on the bottom and side slopes of the channels were taken with a level and rod to the nearest tenth of a foot, and were taken at intervals of 5 feet across the channel and at all points where a change in slope occurred. For the larger channels the measurements in the water section were generally taken from a boat attached to a rope stretched across the stream and fastened securely on both sides.

### COMPUTATIONS.

In the experimental determination of the value of $n$ in Kutter's formula,

$$C=\frac{41.6+\frac{1.811}{n}+\frac{0.00281}{S}}{1+\left(41.6+\frac{0.00281}{S}\right)\frac{n}{\sqrt{R}}}$$

the coefficient $C$ is first obtained from Chezy's formula,

$$V = C\sqrt{RS}$$

and then the value of $n$ by solving for $n$ in Kutter's formula. In solving Chezy's formula for $C$ the following terms must be known:

$V$, the mean velocity along the slope course.

$R$, the mean hydraulic radius along the slope course.

$S$, the mean slope of the water surface along the slope course.

As has been explained, the data required for computing these values were obtained by field measurements. The mean velocity, $V$, was determined by dividing the discharge by the mean cross-sectional area of the channel along the slope course. The discharge was computed from the soundings and velocity measurements made at the gauging section. The method of computing the discharge was as follows: The mean velocity in the vertical at each velocity measuring point was obtained by taking one-sixth of the sum of the velocity at the surface, four times the velocity at mid depth, and the velocity at the bottom, or by taking the mean of the velocities obtained at 0.2 and 0.8 depths. The mean velocity for each section between the verticals was taken as the average of the mean velocities for the verticals on either side of the section, and the discharge for each section was obtained by multiplying the mean velocity for the section by the area of the section. The total discharge of the stream was obtained by taking the sum of the discharges for all sections across the stream.

The cross-sectional measurements were platted on cross-section paper, on a scale of 5 or 10 feet to the inch, depending upon the size of the channel. The areas and wetted perimeters for each cross section were obtained by means of a planimeter and map measurer. The mean cross-sectional area, which was used in determining the mean velocity for the course, was obtained by taking the average of all the cross-sectional areas along the course.

For some of the channels the mean hydraulic radius for the course was obtained by taking the average of all the hydraulic radii as computed for each cross section; for others it was obtained by dividing the mean cross-sectional area by the average of all the wetted perimeters as determined for each cross section along the course. There was no appreciable difference in the results obtained by the use of the two methods unless the channel was subject to large variations in cross section, in which case the first method was used.

On all of the channels the slope of the water surface was practically uniform from the upper to the lower ends of the slope courses, and the differences in the velocities at the upper and lower ends of the courses were so small that the application of a correction for the difference in velocity heads was found to be unnecessary, so far as the practical value of the results was concerned.

In calculating values of *n,* the values of *V, R,* and *S* were first determined as explained in the foregoing, C was then computed by Chezy's formula, and with *C, R,* and *S* known, the value of *n* was obtained from a large-scale diagram similar to, but larger than, the one bound in the treatise, "The Flow of Water in Rivers and Other Channels," by Ganguillet and Kutter, as translated by Hering and Trautwine.

## TABULATED RESULTS.

In Tables 1 to 6 are given the hydraulic elements and values of C and *n* for the six different sets of experiments. In the third column is shown the average of the maximum depths as measured at each of the cross sections. At the foot of this column is shown the average maximum depth for a bankful stage of each channel, which enables the reader to estimate about what proportion of the channel is filled for each measurement. In the fourth column is given the average surface width along the slope course at the time of each measurement. With these two dimensions, the average cross-sectional area given in column 6, and the accompanying cross-sectional figures for each channel, a good idea can be obtained as to the shape and size of the channel. The headings at the tops of the other columns in the tables are self-explanatory. On most of the channels values of *n* were determined for several stages ranging from low to high.

Attention is called to the specially interesting features of some of the experiments. For instance, values of *n* for Old Town Creek, Table 1, were obtained before and after clearing, in order to show the effect upon *n* as produced by the presence of growth in the channel.

On the South Forked Deer River at Campbell's levee, near Jackson, Tenn., experiments were conducted to determine the relative values of *n* for three consecutive courses of channel; the first, an old straight course of the river channel; the second, an old crooked course of the river channel; and the third, a course of an irregularly dredged channel. The results which are given in Table 3, show a remarkable difference in the values of *n* obtained for the three different conditions of channel.

In the results of the Iowa experiments (Table 4) attention is called to the unusually low values of *n* obtained for earth channels. These low values, which were obtained for Boyer River and Allen and Willow Creeks, were due, no doubt, to the smoothing up of irregularities by silting and to the lubricating effect of silty mud deposited on the bottom and side slopes of the channels. The increase in the value of *n,* due to a caving bank covered with a heavy growth, is shown by the experiments made on the Little Sioux River cut-off channel before and after the caving took place.

The increase in the value of *n*, due to the growth of grass in channels, is shown by the results of the experiments made in North Carolina (Table 5). These experiments were made during the winter and the following summer, before and after the growth of grass in the channels.

## DESCRIPTION OF CHANNELS.

At the right-hand side of each of the Tables 1 to 6 is given a complete description of the drainage channel. These detailed descriptions, supplemented by the views of the channels shown in the plates, are intended to assist the engineer in the proper choice of *n* for his particular use. Under the description of channels are included the factors or conditions that influence the flow of water in a channel. These factors are described under the following headings: Course, cross section, side slopes, bottom, soil, and condition. Also the approximate date when the channel was constructed is given, from which can be determined the age of the channel at the time the experiments were made.

### COURSE.

The length and alignment of the course of channel are discussed under this heading. Where the length of the course is unduly short, the probability of error in the slope measurements is somewhat greater than where it is comparatively long. It was impossible in many instances, other governing factors being duly considered, to follow the general rule adopted, namely, that the length of the slope course should be at least 10 times the top width of the channel. With the exception of two courses of channels, the alignment of the slope courses was practically straight. These exceptions consisted of a bend in the Sugar Creek channel and of several irregular crooks in the old river channel at Campbell's levee, near Jackson, Tenn. (Table 3).

### CROSS SECTION.

Under this heading variations in the shape of the cross section along the courses are noted, and the reader is referred to figures 2, 4, 6, 8, 10, and 12, which show the per cent variation from the average cross-sectional area for all cross sections along the slope courses. In most cases this per cent variation is shown for low, medium, and high stages. From these figures an idea can be obtained as to the progressive changes in size of the channel along the courses and whether these changes are gradual or abrupt. For instance, in figure 2 *A*, it is seen that the per cent variations are much larger and the changes in size of the channel along the course are much more abrupt for the low than for the high stage, which accounts largely for the higher values of *n* obtained for the low stages as recorded in Table 1.

It was found that abrupt changes in the size of a channel that are repeated at short intervals are often alone responsible for the high values of $n$ obtained.

Figures 1, 3, 5, 7, 9, and 11 show the average cross sections for all of the channels. From these a general idea can be obtained as to the size and shape of the various channels.

### SIDE SLOPES AND BOTTOM.

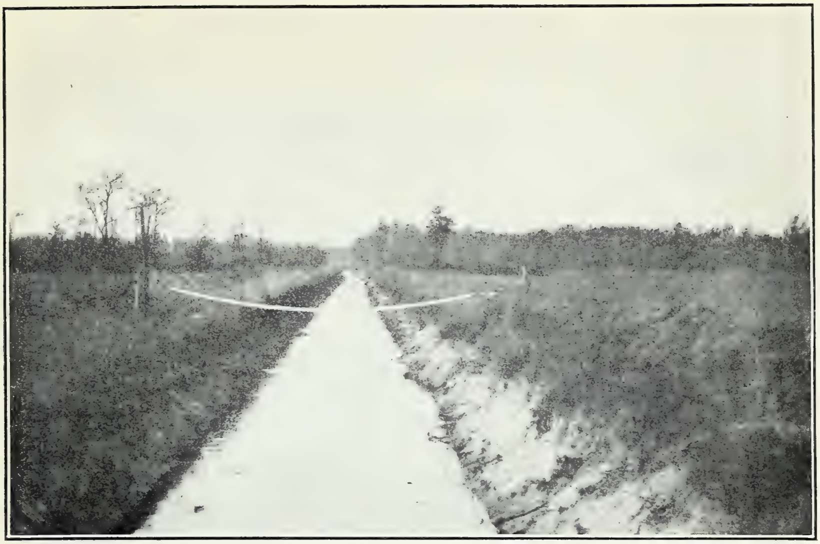
Irregularities in the perimeter of the channel are discussed under the two headings, side slopes and bottom, for the reason that the bottom alone is often the chief retarding factor during low stages. Irregularities in the perimeters of channels have a very decided effect upon the value of $n$. For instance, irregularities in the side slopes of the South Forked Deer River near Jackson, Tenn., were largely responsible for the higher values of $n$ obtained for this course than were obtained for the same channel near Roberts, Tenn., where the side slopes were much more regular (Table 3). The irregularities in the channel at Jackson were due to rough finishing work with the dredge at the time of construction. To smoothness of perimeter may be attributed in part the low values of $n$ obtained for the Allen and Willow Creek channels in western Iowa (Table 4).

### SOIL.

Under this heading descriptions of the different types of soils found in the various channels are given. However, no noticeable difference in the retarding effect of the different soils was detected. All of the soils are of an alluvial nature, the bottoms through which the ditches were dug having been built up by deposits of silt brought down from the hills during heavy rains.

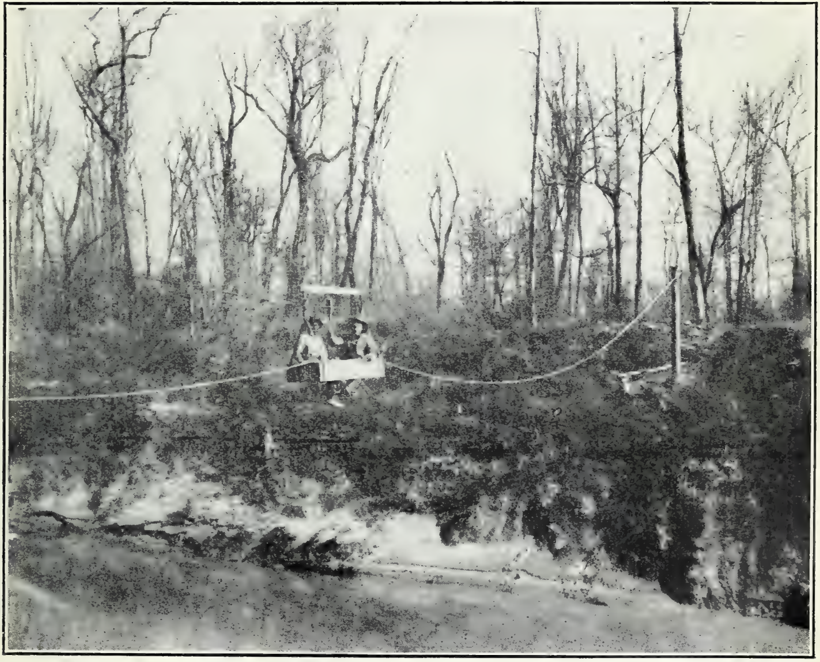
### CONDITION.

An effort has been made to describe accurately the condition of the channels at the time the measurements were made. Mention is made of all sorts of growth, obstructions, and débris—factors which are in many instances responsible for the high values of $n$ obtained. The pronounced effect of vegetation, such as grass, in a channel is clearly shown by the experiments made on three of the channels in North Carolina (Table 5), of the effect of small growth, such as weeds, bushes, and saplings by the experiments on Old Town Creek (Table 1), and of the effect of large obstructions, such as logs, fallen trees, and débris by the experiments on the South Forked Deer River at Campbell's levee, near Jackson, Tenn. (Table 3). Whether or not much erosion has taken place in the channel is also mentioned under this heading.



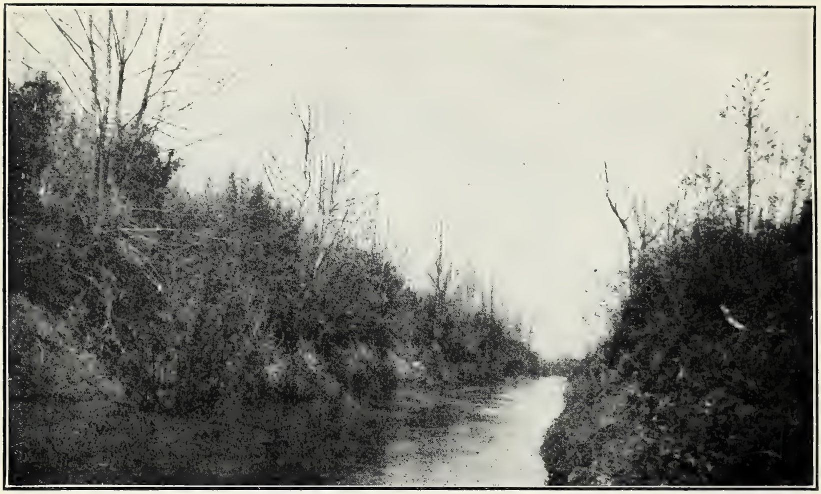
B. P. R.—D2627.

FIG. 1.—TYPICAL SUSPENSION FOOTBRIDGE GAGING STATION, MUD CREEK, LEE COUNTY, MISS.



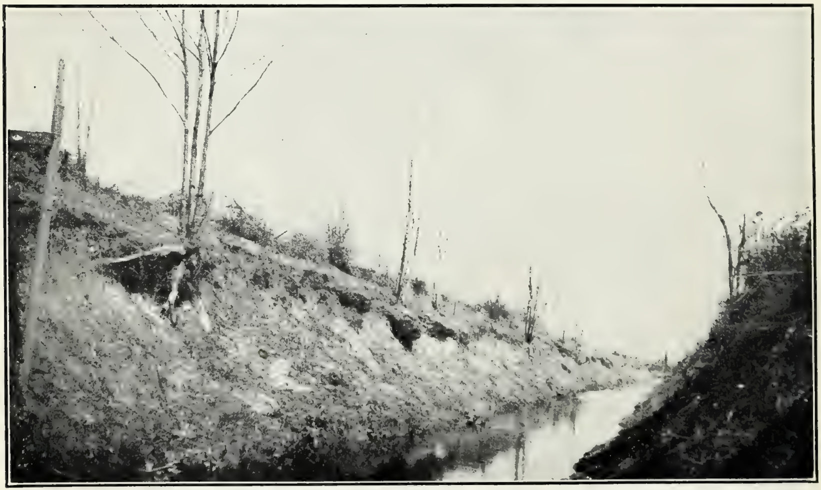
B. P. R.—D74

FIG. 2.—CABLE GAGING STATION ON THE BOGUE PHALIA CHANNEL, NEAR HELM, MISS.



B. P. R—D2517

FIG. I.—SLOPE COURSE OF OLD TOWN CREEK DREDGED CHANNEL, NEAR TUPELO, MISS. BEFORE CLEARING, 1913. (SEE TABLE NO. I.)



B. P. R.—D2516

FIG. 2.—SAME VIEW AS ABOVE, AFTER CLEARING, 1914.

#### WHEN CONSTRUCTED.

The age of the channel at the time the experiments were made may be obtained by referring to this heading and to column 2; the former shows approximately when the channel was constructed and the latter the date when the experiments were made. The time elapsed since the construction of a dredged channel is to some extent a measure of the condition of the channel as regards growth and other obstructions to flow, except where the channel has been carefully maintained. It is also a measure of the probable extent of erosion or silting that has occurred in the channel since construction. The growth of vegetation in a channel checks erosion and promotes silting, but on the other hand active erosion in a channel checks and often entirely prevents the growth of vegetation.

Low values of *n* are generally found for properly finished, newly dredged channels of uniform cross section, as was the case for Mud Creek (Table 1) and South Forked Deer River, near Roberts, Tenn. (Table 3). The effect of erosion on such a channel is to make it more irregular and thereby to increase the value of *n*. However, after a certain amount of erosion has taken place it does not necessarily follow that further erosion will tend to increase the irregularity of the channel, as may be seen from the results obtained for the North Forked Deer River near Trenton, Tenn. (Table 3).

### ACCURACY OF RESULTS.

With few exceptions there are no reasons to suspect inaccuracies in the result of these experiments. The gauging sections and slope courses were so selected as to remove as far as possible the probability of large errors in the field measurements. In some instances, which will be mentioned under the separate discussion of each channel, favorable sites for gauging stations and slope courses were not obtained. Where no mention is made as to the reliability of the results, it may be inferred that the results obtained are entirely reliable. Comparatively speaking, the most accurate results were obtained for the high stages in the various channels, since there was a greater probability of error in the gaugings and cross-sectional measurements for the lower stages.

### DESCRIPTION OF EXPERIMENTS.

A description of the six sets of experiments and a discussion of the results obtained are given in the following pages.

#### EXPERIMENTS IN LEE COUNTY, MISS.

Experiments were conducted on five dredged channels in Lee County, Miss., namely: Old Town Creek, Mud Creek, Twenty Mile Creek, Connewah Creek, and Chawappah Creeks (see Table 1).

TABLE 1.—*Results of experiments made in Lee County, Miss.*

OLD TOWN CREEK DREDGED CHANNEL NEAR TUPELO, MISS. (BEFORE CLEARING), 1913.

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V = C\sqrt{RS}$ $C$. | Coefficient of roughness $n$. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Feet.* | *Feet.* | *Second-feet.* | *Sq. ft.* | *Ft. per sec.* | *Feet.* | | | | |
| 1 | Mar. 4, 1913 | 5.4 | 22.9 | 95.3 | 76.2 | 1.25 | 2.90 | 0.000518 | 32.2 | 0.0550 | *Course*, straight; 1,224 feet long. *Cross section*, slight and gradual variations in shape; for variation in size, see fig. 2 A. *Side slopes*, right side irregular, left side very irregular. *Bottom*, irregular and uneven. *Soil*, varies from black waxy clay at top to yellow clay at bottom. *Condition*, right side slope and part of bottom practically covered with small saplings, brush, and cane; occasional growths of vegetation on other side slopes. *Constructed*, Dec. 1907. (See Pl. II, fig. 1; and fig. 1 A.) |
| 2 | Mar. 3, 1913 | 5.8 | 22.0 | 125.7 | 85.5 | 1.47 | 3.12 | .000513 | 36.8 | .0490 | |
| 3 | Mar. 24, 1913 | 6.7 | 25.9 | 179.6 | 108.2 | 1.66 | 3.55 | .000444 | 41.8 | .0450 | |
| 4 | Mar. 21, 1913 | 10.8 | 34.9 | 500.7 | 231.8 | 2.16 | 5.30 | .000388 | 47.6 | .0433 | |
| 5 | Apr. 4, 1913 | 11.7 | 35.5 | 579.4 | 261.0 | 2.22 | 5.78 | .000445 | 43.8 | .0480 | |
| 6 | Feb. 27, 1913 | 12.6 | 39.0 | 674.0 | 298.2 | 2.26 | 5.95 | .000452 | 43.5 | .0490 | |
| 7 | Mar. 14, 1913 | 13.6 | 45.2 | 823.0 | 341.5 | 2.41 | 6.06 | .000375 | 50.5 | .0420 | |
| | .............. | [1] 13.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |

OLD TOWN CREEK DREDGED CHANNEL NEAR TUPELO, MISS. (AFTER CLEARING), 1914.

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V = C\sqrt{RS}$ $C$. | Coefficient of roughness $n$. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | Mar. 5, 1914 | 4.0 | 19.5 | 45.0 | 50.0 | 0.90 | 2.28 | 0.000358 | 31.5 | 0.0520 | Description of channel practically the same as the above, except for remarks under *Condition*.<br>*Condition*, all brush, vegetation, and obstructions to flow were cleared from the course of channel and for 500 feet above the upper end of the course, and for the same distance below the lower end. (See Pl. II, fig. 2.) |
| 9 | Mar. 20, 1914 | 4.3 | 20.0 | 59.7 | 58.0 | 1.03 | 2.43 | .000350 | 35.3 | .0475 | |
| 10 | Apr. 17, 1914 | 4.65 | 21.0 | 77.9 | 60.4 | 1.29 | 2.55 | .000377 | 41.6 | .0410 | |
| 11 | Apr. 9, 1914 | 5.3 | 22.2 | 105.4 | 74.2 | 1.42 | 2.85 | .000292 | 49.2 | .0356 | |
| 12 | Apr. 3, 1914 | 5.4 | 23.0 | 120.0 | 80.0 | 1.50 | 2.90 | .000312 | 49.8 | .0355 | |
| 13 | Apr. 13, 1914 | 6.6 | 26.4 | 185.1 | 107.0 | 1.73 | 3.37 | .000271 | 57.4 | .0320 | |
| 14 | Mar. 26, 1914 | 6.7 | 26.5 | 218.2 | 110.2 | 1.98 | 3.42 | .000305 | 61.4 | .0299 | |
| 15 | Mar. 12, 1914 | 7.1 | 27.5 | 240.0 | 120.0 | 2.00 | 3.53 | .000290 | 62.5 | .0294 | |
| 16 | Mar. 26, 1914 | 7.1 | 27.6 | 242.4 | 120.0 | 2.02 | 3.58 | .000279 | 64.0 | .0290 | |
| 17 | .....do....... | 7.4 | 28.0 | 260.4 | 127.0 | 2.05 | 3.69 | .000267 | 65.3 | .0286 | |
| 18 | Apr. 13, 1914 | 8.1 | 29.8 | 310.2 | 142.3 | 2.18 | 3.95 | .000271 | 66.6 | .0285 | |
| 19 | May 5, 1914 | 11.6 | 37.5 | 710.2 | 265.0 | 2.68 | 5.70 | .000346 | 60.3 | .0340 | |
| 20 | Mar. 30, 1914 | 12.4 | 39.7 | 815.6 | 295.5 | 2.76 | 5.95 | .000268 | 69.1 | .0297 | |
| 21 | May 6, 1914 | 12.7 | 41.0 | 882.2 | 307.4 | 2.87 | 6.05 | .000346 | 62.8 | .0332 | |
| | .............. | [1] 13.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |

Mud Creek Dredged Channel near Tupelo, Miss.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | Apr. 11, 1914 | 2.6 | 18.5 | 54.8 | 40.0 | 1.37 | 1.8 | 0.000300 | 59.0 | 0.0267 | *Course*, straight; 1,194 feet long. *Cross section*, very little variation in shape; for variation in size see fig. 2 B. *Side slopes*, quite regular. *Bottom*, even and regular. *Soil*, sandy, waxlike clay. *Condition*, newly dredged channel; no vegetation or obstructions of any sort in channel. *Constructed*, January, 1913. (See Pl. III, fig. 1; and fig. 1 B.) |
| 23 | .....do....... | 2.8 | 19.3 | 61.9 | 43.0 | 1.44 | 1.9 | .000305 | 59.8 | .0268 | |
| 24 | Apr. 7, 1914 | 2.9 | 19.5 | 64.8 | 43.2 | 1.50 | 1.9 | .000305 | 62.3 | .0257 | |
| 25 | Apr. 9, 1914 | 3.2 | 20.5 | 74.9 | 47.7 | 1.57 | 2.1 | .000310 | 61.5 | .0267 | |
| 26 | Apr. 5, 1914 | 3.8 | 22.0 | 115.0 | 57.5 | 2.00 | 2.3 | .000301 | 76.0 | .0224 | |
| 27 | Mar. 28, 1914 | 4.0 | 22.6 | 125.0 | 61.0 | 2.05 | 2.5 | .000349 | 69.3 | .0247 | |
| 28 | Mar. 26, 1914 | 4.1 | 22.8 | 130.2 | 62.6 | 2.08 | 2.6 | .000336 | 70.4 | .0246 | |
| 29 | .....do....... | 4.9 | 24.7 | 192.7 | 88.0 | 2.19 | 2.9 | .000321 | 71.8 | .0247 | |
| 30 | Mar. 27, 1914 | 4.95 | 24.8 | 199.1 | 88.5 | 2.25 | 2.9 | .000349 | 70.7 | .0250 | |
| 31 | Apr. 8, 1914 | 5.0 | 24.9 | 203.4 | 90.0 | 2.26 | 3.0 | .000340 | 70.8 | .0251 | |
| 32 | May 5, 1914 | 9.9 | 32.5 | 762.8 | 225.0 | 3.39 | 5.3 | .000364 | 77.2 | .0258 | |
| 33 | Mar. 29, 1914 | 10.65 | 34.5 | 904.0 | 252.5 | 3.58 | 5.6 | .000378 | 77.8 | .0259 | |
| 34 | .....do....... | 10.70 | 34.5 | 914.4 | 254.0 | 3.60 | 5.6 | .000393 | 76.8 | .0263 | |
| | .............. | [1] 11.50 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |

Twenty Mile Creek Dredged Channel near Baldwyn, Miss.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 35 | Mar. 28, 1913 | 4.5 | 24.0 | 120.0 | 75.5 | 1.59 | 2.75 | 0.000194 | 68.9 | 0.0254 | *Course*, straight; 324 feet long. *Cross section*, slightly abrupt variations in shape; for variation in size, see fig. 2 C. *Side slopes*, lower, quite regular; upper, quite irregular, due to caving of banks. *Bottom*, quite even and regular. *Soil*, waxy clay loam; contains some sand. *Condition*, channel practically free from vegetation; great many roots along upper part of channel; erosion very active during high stages. *Constructed*, January, 1910. (See Pl. III, fig. 2; and fig. 1 C.) |
| 36 | Mar. 27, 1913 | 6.4 | 30.8 | 288.1 | 124.7 | 2.31 | 3.60 | .000382 | 62.3 | .0298 | |
| 37 | Apr. 10, 1913 | 12.1 | 40.0 | 1,312.8 | 328.2 | 4.00 | 6.50 | .000800 | 55.5 | .0380 | |
| 38 | .....do....... | [1] 13.7 | 42.4 | 1,730.3 | 384.5 | 4.50 | 7.15 | .001150 | 49.6 | .0440 | |

Chawappah Creek Dredged Channel near Shannon, Miss.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | Feb. 5, 1913 | 2.8 | 18.7 | 75.0 | 41.0 | 1.83 | 1.95 | 0.000850 | 44.9 | 0.0357 | *Course*, straight; 320 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 2 D. *Side slopes*, quite regular except near top and along edge of bottom. *Bottom*, quite regular. *Soil*, varies from a sandy loam at top to a waxy clay at bottom. *Condition*, very little vegetation in channel; irregularity of upper part of channel due to erosion. *Constructed*, May, 1911. (See Pl. IV, fig. 1; and fig. 1 D.) |
| 40 | Apr. 5, 1913 | 7.3 | 31.2 | 368.1 | 156.0 | 2.36 | 4.20 | .000406 | 57.1 | .0338 | |
| 41 | Feb. 28, 1913 | 11.1 | 36.4 | 1,152.6 | 282.5 | 4.08 | 6.05 | .000935 | 54.2 | .0385 | |
| | .............. | [1] 12.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |

Coonewah Creek Dredged Channel near Shannon, Miss.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | Apr. 4, 1913 | 10.6 | 36.7 | 850.0 | 286.2 | 2.97 | 5.95 | 0.000620 | 48.9 | 0.0430 | *Course*, straight; 450 feet long. *Cross section*, rather gradual variations in shape; for variations in size, see fig. 2 E. *Side slopes*, very irregular. *Bottom*, irregular and uneven. *Soil*, clay loam. *Condition*, some grass and other vegetation on side slopes; bottom free from growth. *Constructed*, May, 1909. (See Pl. IV, fig. 2; and fig. 1 E.) |
| | .............. | [1] 12.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |

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[1] Average maximum depth at bankful stage.

### OLD TOWN CREEK.

Measurements were made on this channel early in 1913 and in 1914. A straight course of 1,224 feet below the steel highway bridge, one-half mile east of Tupelo, Miss., was selected for making the measurements. The discharge measurements for 1913 were made from the highway bridge and those for 1914 from a suspension footbridge constructed near the upper end of the course. The latter gaging section was much more desirable for accurate measurements than the former one.

An experiment for determining the effect upon the flow in the channel, due to the clearing of brush and other resistances to flow, was conducted on Old Town Creek. No clearing was done for the measurements during 1913. One side slope of the channel and part of the bottom were practically covered with small saplings, brush, and cane, and were quite irregular. The other side slope was comparatively smooth and uniform. For the measurements during 1914 all brush, logs, and other obstructions were cleared from the course of the channel and for 500 feet above the upper end and for the same distance below the lower end of the slope course, so that a comparison could be made as to the relative values of *n* before and after clearing. The slope of the left bank was quite regular while that of the righ bank was extremely irregular, a condition due to the growth of brush causing the bank to erode unevenly. The soil in the bottom and sides of the ditch was quite hard. The views shown in Plate II give a good idea of the conditions existing in the channel before and after clearing. (See also fig. 1 *A*, for average cross section of the channel.)

In Table 1, measurements 1 to 21, are given the values obtained for *n*, together with the various observed hydraulic elements. It is obvious, from the values of *n* obtained before and after clearing, that the efficiency of a channel is greatly decreased by permitting the growth of vegetation in it.

During low water the uniform fall of the surface of the water was interrupted by irregularities in the bottom and sides of the channel. For such conditions the hydraulic grade throughout the section consisted of a series of comparatively steep slopes followed by flatter ones, due to the depth of water being so small that the irregularities in the channel gave rise to quite appreciable variations in area of cross section from point to point, thus causing variations in velocity and in the hydraulic grade (see fig. 2 *A*). As a result the values of *n* obtained for low water conditions are high. The total loss of head throughout the course under such conditions is the sum of the loss due to the roughness of the wetted perimeter and the quite appreciable losses in shock and eddies that occur where the hydraulic gradient changes from a steeper to a flatter slope and where the cross section

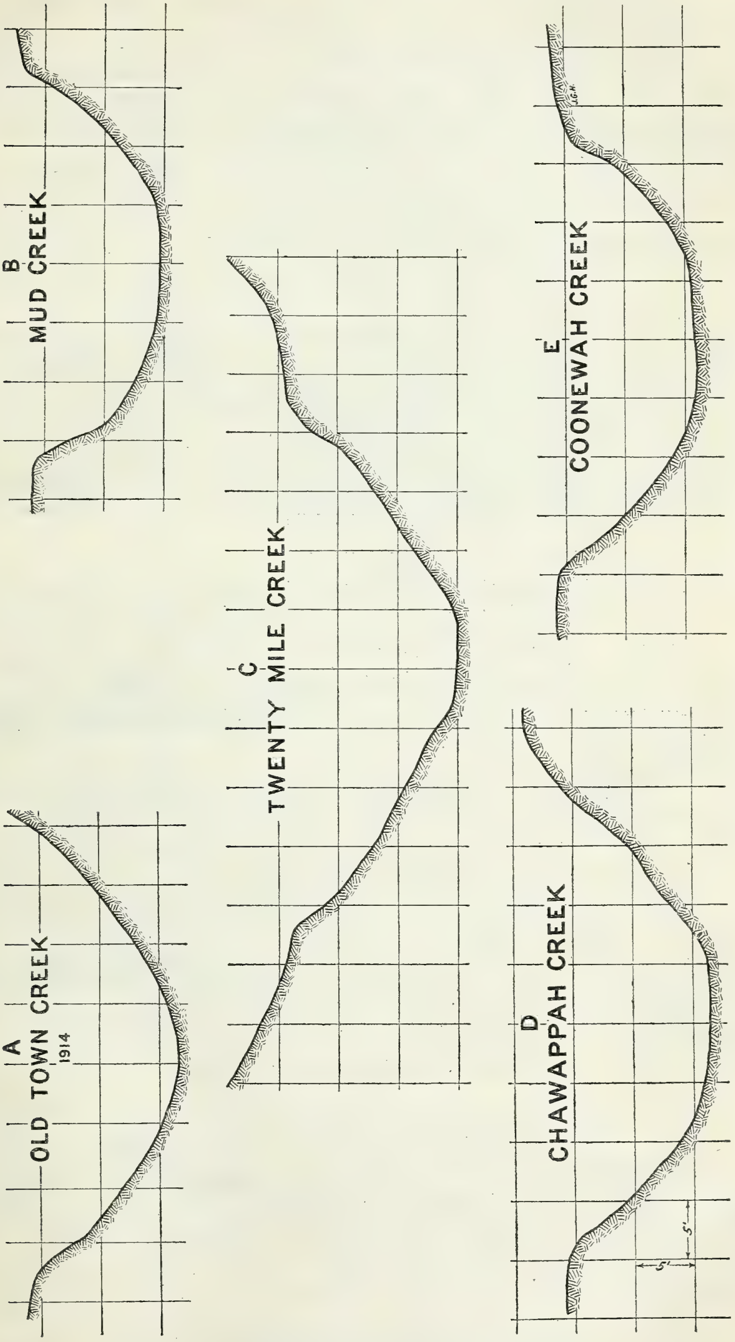

FIG. 1.—Average cross sections of channels for experiments in Lee County, Miss.

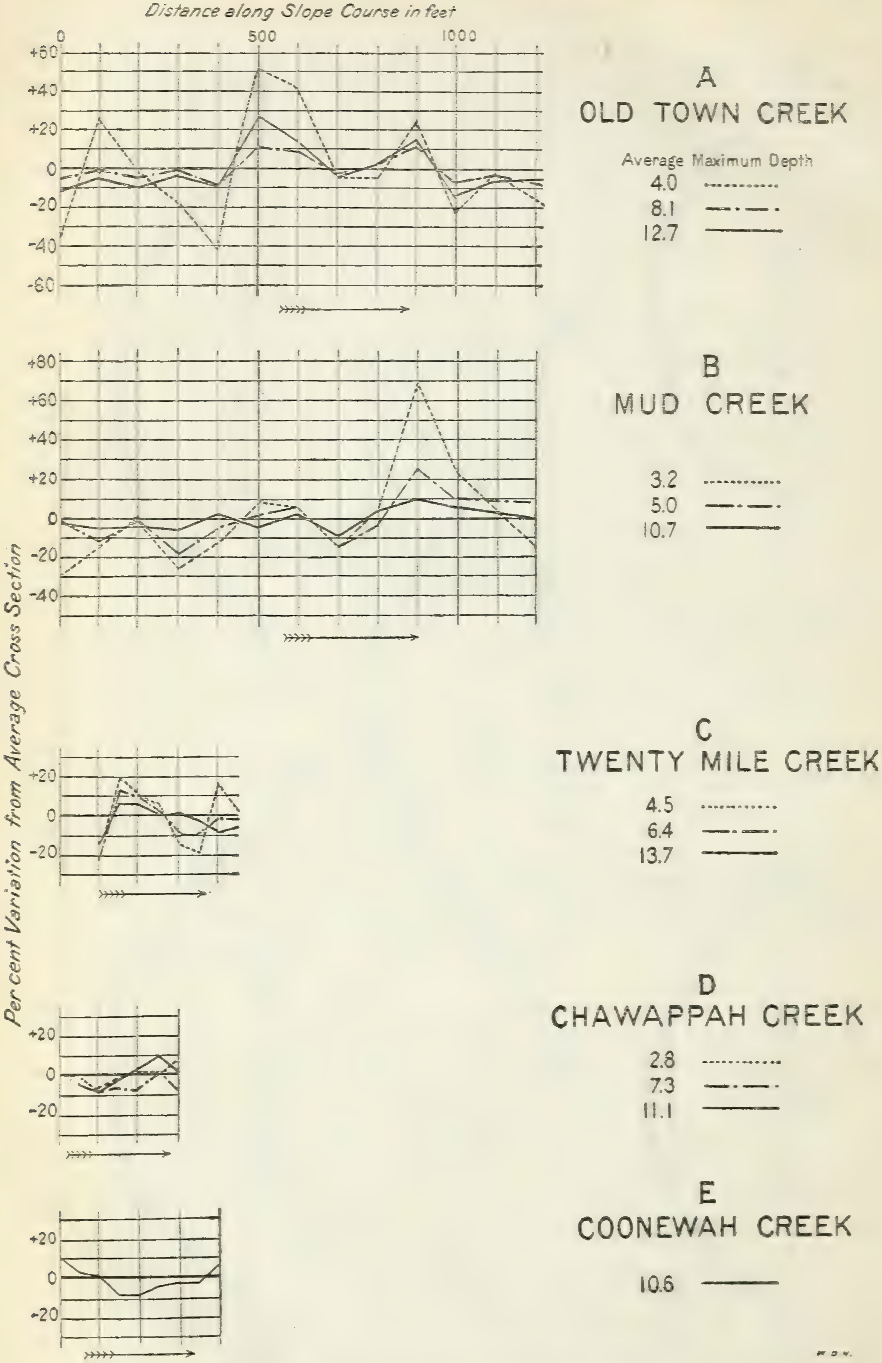

FIG. 2.—Graphs for experiments in Lee County, Miss., showing per cent variation from average cross-sectional area, for all cross sections along slope courses.

of flow changes. For low water conditions the loss in shock and eddies is quite appreciable, and as the values of $n$ were obtained by directly measuring this total loss of head throughout the course these values would be necessarily large. The table shows that for such conditions the value of $n$ decreases as the depth increases. This would be expected, for as the depth increases the second factor mentioned above becomes comparatively smaller, and the total loss of head thus becomes to a greater extent due to roughness of wetted perimeter and to a less extent due to the influence of eddies and shock.

In measurement No. 9, Table 1, for $n=0.0475$ the discharge is 60 second-feet; that for $n=0.030$,[1] and the same hydraulic elements, is 96 second-feet. $\frac{96-60}{60}\times 100=60$ per cent. That is, the capacity of the lower part of the channel for low water could be increased 60 per cent by eliminating irregularities in the bottom slope and abrupt changes in cross section. As will be seen later, the bottom slope and cross section of Mud Creek are practically free from irregularities, and the values of $n$ do not vary much from low to high-water flow.

### MUD CREEK.

Measurements were made on this channel during the early part of the year 1914. For the slope measurements a straight course 1,194 feet long was selected above the highway bridge about 1 mile east of Tupelo. A suspension footbridge was constructed at a site where conditions were ideal for making accurate current meter measurements.

A good idea of the condition and regularity of the channel can be obtained from Plate III, figure 1. Although in the same valley, the soil is decidedly different from that found in Old Town Creek. This part of the bottom land is made up of sediment carried from the eastern part of the Mud Creek watershed, where the soil contains considerable sand. The soil in the channel is a sandy, waxlike clay that erodes very easily. This was a comparatively new channel at the time of these experiments, the ditch having been finished in January, 1913; and, although it had eroded to some extent, it had retained its original uniform slope and comparatively uniform cross-sectional area (see figs. 1 *B*, and 2 *B*).

In Table 1, measurements 22 to 34, are shown the various hydraulic elements of Mud Creek as computed from field measurements, and the values of $n$ obtained. That for all stages of Mud Creek is about 0.025, while that obtained for the higher stages in Old Town Creek, after clearing, is about 0.030. The lower value of $n$ as obtained for Mud Creek can readily be ascribed to the facts that this is a more recently constructed channel and that the bottom slope and cross-sectional area are more uniform throughout the course than for Old Town Creek.

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[1] See measurements 22–26, Table 1.

### TWENTY-MILE CREEK.

The slope course on Twenty-Mile Creek was rather short, being 324 feet in length, and was located below the highway bridge 1 mile east of Baldwyn, Miss. (see Pl. III, fig. 2; and figs. 1 *C*, and 2 *C*). The lower part of the channel was quite smooth and regular, but the upper part and edge of bank were irregular. The channel is eroding rapidly, and many stumps along the banks have been undermined and fallen into the channel. Table 1 shows the hydraulic elements and the values of *n* obtained for Twenty-Mile Creek. The value of *n* increases as the stage increases, due no doubt to the irregularities in the wetted perimeter for the higher stages. The soil in the channel is a waxy clay loam, and in some parts of the channel contains considerable sand.

### CHAWAPPAH CREEK.

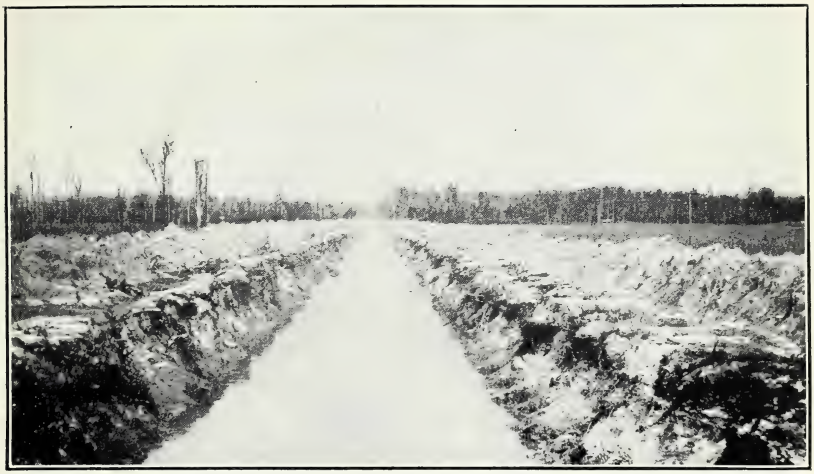
Slope measurements for Chawappah Creek were made on a rather short course (320 feet long) between the highway and railroad bridge, one-half mile south of Shannon, Miss. The gauging section was located at the highway bridge. The view of Chawappah Creek for low water (Pl. IV, fig. 1), shows very well the condition of the channel. The soil varies from a sandy loam to a waxy clay, and the sides and bottom were quite hard. The channel is eroding very rapidly, which is partly the cause of the turbulent water surface and the resulting comparatively high values of *n*. The average value obtained for *n* was about 0.035 (see figs. 1 *D*, and 2 *D*).

### COONEWAH CREEK.

Only one observation for slope was made on Coonewah Creek. The value computed for *n* was 0.0430. Plate IV, figure 2, shows the course on which the slope was measured and the condition of the channel. The soil is quite similar to that found on Chawappah Creek, but erosion has not been as active as on the latter (see figs. 1 *E*, and 2 *E*).

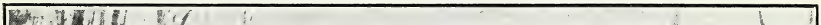
### DISCUSSION OF LEE COUNTY EXPERIMENTS.

Of the experiments made in Lee County, Miss., the results obtained from those on Old Town and Mud Creeks are the most reliable. It appears that for conditions of flow the value of *n* for channels similar to Mud Creek is 0.025, which means that the bottom and sides should be fairly regular and free from any form of obstruction to flow, and the slope and cross-sectional area practically uniform. These conditions generally obtain only in new ditches, and it would therefore not be wise to use a coefficient as low as 0.025 in the design of channels, since the efficiency of a channel generally decreases with age, as



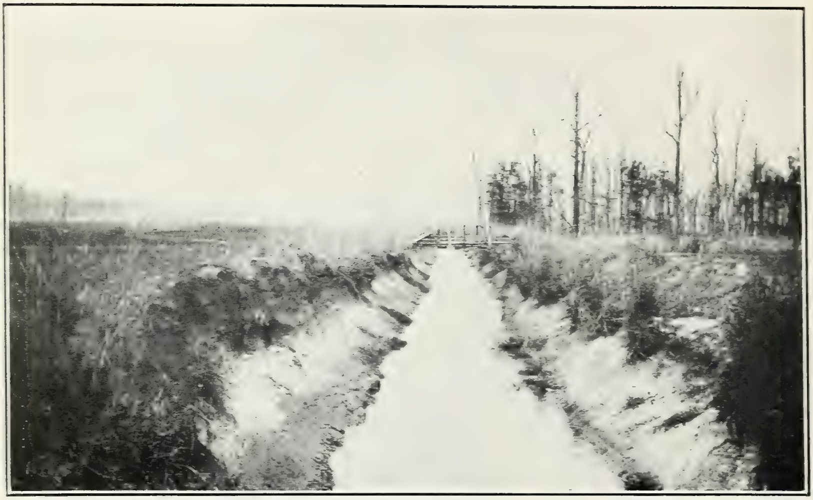
B. P. R.–D1645

FIG. 1.—SLOPE COURSE OF MUD CREEK DREDGED CHANNEL, NEAR TUPELO, MISS., 1913. (SEE TABLE NO. 1.)



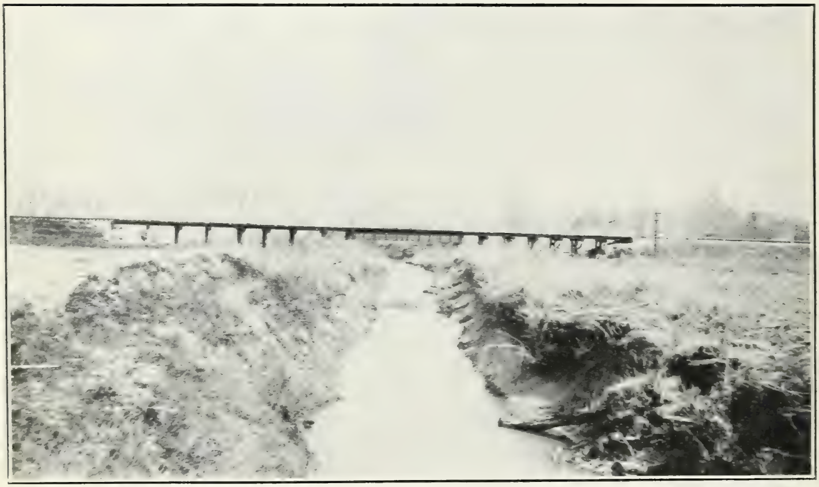
B. P. R.–D1650

FIG. 2.—SLOPE COURSE OF TWENTY MILE CREEK DREDGED CHANNEL, NEAR BALDWYN, MISS., 1913. (SEE TABLE NO. 1.)



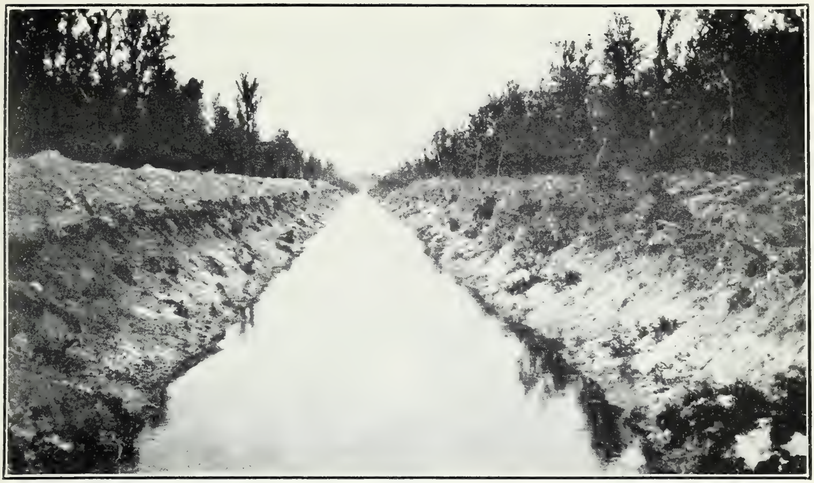
B. P. R.—D1638

FIG. 1.—SLOPE COURSE OF CHAWAPPAH CREEK DREDGED CHANNEL, NEAR SHANNON, MISS., 1913. (SEE TABLE NO. 1.)



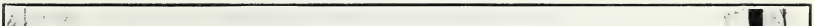
B. P. R.—D1634

FIG. 2.—SLOPE COURSE OF COONEWAH CREEK DREDGED CHANNEL, NEAR SHANNON, MISS., 1913. (SEE TABLE NO. 1.)



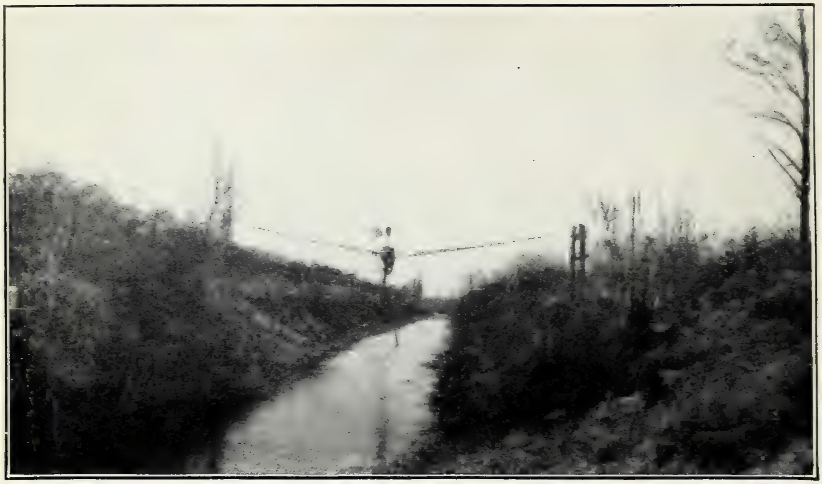
B. P. R.—D481

FIG. 1.—SLOPE COURSE OF BOGUE PHALIA DREDGED CHANNEL, NEAR HELM, MISS., 1915. (SEE TABLE NO. 2.)



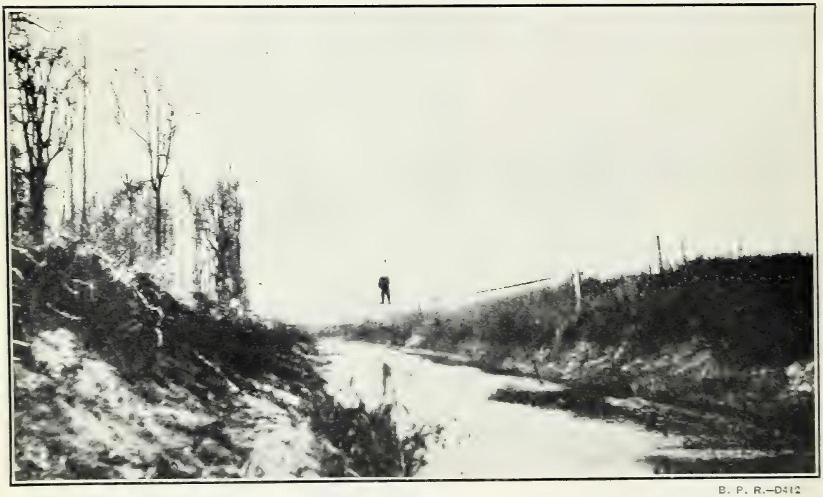
B. P. R.—D3066

FIG. 2.—SLOPE COURSE OF BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS., 1915. (SEE TABLE NO. 2.)



B. P. R.—D409

FIG. 1.—SLOPE COURSE OF PECAN BAYOU DREDGED CHANNEL, NEAR SHAW, MISS., 1915. (SEE TABLE NO. 2.)



B. P. R.—D412

FIG. 2.—SLOPE COURSE OF WEST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS., 1915. (SEE TABLE NO. 2.)

is shown by the experiments on Old Town Creek. It is believed that if the ditches are kept in good order the value of $n$ can be maintained at approximately 0.030 for this section of country. If this value of $n$ is to be maintained systematic maintenance work from the time the ditch is first constructed is necessary.

### EXPERIMENTS IN BOLIVAR COUNTY, MISS.

The experiments in Bolivar County, Miss., were made on the following streams: Bogue Phalia, Bogue Hasty, Pecan Bayou, West Bogue Hasty, and East Bogue Hasty.

#### BOGUE PHALIA.

The conditions for the accurate discharge and slope measurements on this channel were ideal. A straight course of practically uniform cross section was selected for slope measurements, about half a mile above the Yazoo & Mississippi Valley Railroad bridge, 2 miles from Helm. The length of the course was 1,003 feet. The gauging station was located near the lower end of the course, and the velocity measurements were made from a movable car suspended from a steel cable which was stretched across the stream at right angles to the direction of flow and supported by upright poles on either bank (Plate I, fig. 2).

The left side slope of Bogue Phalia, along the course, was quite regular while the right side was subject to caving and was only fairly regular. The channel was very smooth for low stages and of uniform section for all stages (fig. 4 A). Very little vegetation of any sort was found in the channel (Plate V, fig. 1; and fig. 3 A). The soil in the lower part of the channel is sandy. The soil in the upper part is a clay loam of close texture and is quite susceptible to caving, particularly when wet.

The slope was indeed an extremely variable quantity. No two measurements of slope were found to be the same, due to the backwater conditions. The greatest slope was found for the lowest stage, and the others varied according to the effect of backwater at the time that measurements were made.

The principal hydraulic elements of the channel and the values of $C$ and $n$ obtained therefrom are shown in Table 2. Little variation was found in the values of $C$, and the values of $n$ were found to vary from 0.0223 for the lowest stage to 0.0313 for the next to the highest stage. As would be expected, the values of $n$ were found to be low for the lower stages, where the channel was quite smooth and uniform in section, and higher for the higher stages, where a greater resistance was offered to flow, by the rougher and more irregular sides of the channel. On the whole, it can be said that this channel was in excellent shape, a fact which is substantiated by the comparatively low values of $n$ obtained.

TABLE 2.—*Results of experiments made in Bolivar County, Miss.*

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ C. | Coefficient of roughness n. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | BOGUE PHALIA DREDGED CHANNEL, NEAR HELM, MISS. |
| | | *Feet.* | *Feet.* | *Second-feet.* | *Sq. ft.* | *Ft. per sec.* | *Feet.* | | | | |
| 1 | Jan. 14, 1915 | 4.20 | 57.5 | 468.5 | 192.0 | 2.44 | 3.11 | 0.000297 | 80.2 | 0.0223 | *Course*, straight; 1,003 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 4 A. *Side slopes*, left side, quite regular; right side, fairly regular. *Bottom*, smooth and even. *Soil*, lower part, sandy clay loam; upper part, clay loam of close texture. *Condition*, excellent, very little vegetation of any sort; lower part of channel more uniform and regular than upper part. *Constructed*, May, 1913. (See Pl. V, fig. 1; and fig. 3 A.) |
| 2 | Feb. 13, 1915 | 6.20 | 63.3 | 678.4 | 320.0 | 2.12 | 4.61 | .000159 | 78.3 | .0247 | |
| 3 | Feb. 11, 1915 | 8.05 | 68.5 | 906.4 | 440.0 | 2.06 | 5.79 | .000132 | 74.5 | .0276 | |
| 4 | Feb. 10, 1915 | 9.45 | 72.5 | 1,102.1 | 535.0 | 2.06 | 6.65 | .000118 | 73.6 | .0292 | |
| 5 | Feb. 9, 1915 | 10.85 | 76.5 | 1,363.2 | 640.0 | 2.13 | 7.49 | .000104 | 76.3 | .0294 | |
| 6 | Jan. 27, 1915 | 11.10 | 77.3 | 1,635.9 | 657.0 | 2.49 | 7.67 | .000127 | 79.9 | .0272 | |
| 7 | Feb. 8, 1915 | 12.20 | 79.8 | 1,650.0 | 750.0 | 2.20 | 8.38 | .000102 | 75.3 | .0300 | |
| 8 | Feb. 2, 1915 | 14.80 | 86.1 | 3,142.8 | 970.0 | 3.24 | 10.00 | .000195 | 73.3 | .0313 | |
| 9 | Feb. 4, 1915 | 14.80 | 86.1 | 2,929.4 | 970.0 | 3.02 | 10.00 | .000165 | 74.3 | .0311 | |
| | ............ | [1] 18.00 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |
| | | | | | | | | | | | BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS. |
| 10 | Jan. 5, 1915 | 2.55 | 38.1 | 50.1 | 74.8 | 0.67 | 1.85 | 0.000152 | 39.9 | 0.0382 | *Course*, straight; 1,039 feet long. *Cross section*, slight and gradual variations in shape; for variations in size, see fig. 4 B. *Side slopes*, right side very irregular and caving badly; left side quite regular. *Bottom*, rather irregular. *Soil*, upper part, dark silty loam; lower part, light yellow clay. *Condition*, upper part right side slope covered with weeds and small tree sprouts; left side slope practically free from vegetation. *Constructed*, September, 1911. (See Pl. V, fig. 2; and fig. 3 B.) |
| 11 | Jan. 20, 1915 | 4.05 | 42.3 | 183.6 | 137.0 | 1.34 | 3.01 | .000183 | 57.1 | .0312 | |
| 12 | Feb. 25, 1915 | 5.60 | 47.2 | 275.9 | 209.0 | 1.32 | 4.08 | .000119 | 59.8 | .0323 | |
| 13 | Feb. 22, 1915 | 5.75 | 47.3 | 366.8 | 210.8 | 1.74 | 4.10 | .000166 | 66.7 | .0285 | |
| 14 | Feb. 23, 1915 | 7.80 | 53.3 | 650.0 | 314.0 | 2.07 | 5.30 | .000169 | 69.2 | .0290 | |
| 15 | Jan. 25, 1915 | [1] 9.50 | 58.2 | 786.6 | 414.0 | 1.90 | 6.31 | .000157 | 60.4 | .0353 | |
| | | | | | | | | | | | PECAN BAYOU DREDGED CHANNEL, NEAR SHAW, MISS. |
| 16 | Feb. 25, 1915 | 4.35 | 20.8 | 36.5 | 67.5 | 0.54 | 2.79 | 0.0000256 | 63.9 | 0.0270 | *Course*, straight; 665 feet long. *Cross section*, slight and gradual variations in shape; for variation in size, see fig. 4 C. *Side slopes*, fairly regular except near the top. *Bottom*, even and regular. *Soil*, dark-colored waxy clay. *Condition*, a few weeds in channel; upper part of channel quite irregular. *Constructed*, July, 1911. (See Pl. VI, fig. 1; and fig. 3 C.) |
| 17 | Feb. 22, 1915 | 4.45 | 21.0 | 53.2 | 70.0 | .76 | 2.85 | .0000676 | 54.7 | .0320 | |
| 18 | Feb. 24, 1915 | 5.85 | 23.5 | 52.3 | 102.6 | .51 | 3.63 | .0000271 | 51.3 | .0366 | |
| 19 | .....do...... | 6.35 | 24.3 | 68.1 | 113.5 | .60 | 3.82 | .0000271 | 59.0 | .0326 | |
| 20 | Feb. 23, 1915 | [1] 6.95 | 25.5 | 110.9 | 127.5 | .87 | 4.04 | .0000782 | 49.0 | .0395 | |

WEST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21<br>22<br>23<br>24 | Feb. 21, 1915<br>Feb. 25, 1915<br>Dec. 31, 1914<br>Feb. 24, 1915 | 2.55<br>4.17<br>5.75<br>5.80 | 26.5<br>29.2<br>32.3<br>32.5 | 32.5<br>66.3<br>81.5<br>107.3 | 59.0<br>97.5<br>143.0<br>145.0 | 0.55<br>.68<br>.57<br>.74 | 2.22<br>2.97<br>3.79<br>3.82 | 0.0001110<br>.0000806<br>.0000515<br>.0000753 | 35.0<br>44.0<br>40.8<br>43.6 | 0.0460<br>.0400<br>.0470<br>.0436 | *Course*, straight; 757 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 4 D. *Side slopes*, fairly regular. *Bottom*, fairly regular. *Soil*, dark-colored waxy clay. *Condition*, channel in good condition with the exception of a few weeds; sediment deposited near lower end of course caused water to stand nearly whole length of course during periods of no flow. *Constructed*, May, 1911. (See Pl. VI, fig. 2; and fig. 3 D. |
| | .............. | [1]8.00 | ........ | .......... | ........ | ........ | ........ | .......... | .......... | ........ | |

EAST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25<br>26<br>27<br>28 | Mar. 31, 1915<br>Feb. 25, 1915<br>Feb. 14, 1915<br>Dec. 31, 1914 | 2.51<br>4.61<br>6.11<br>[1]6.41 | 16.6<br>22.2<br>25.8<br>26.4 | 20.1<br>80.5<br>137.6<br>149.5 | 30.5<br>72.5<br>107.5<br>115.0 | 0.66<br>1.11<br>1.28<br>1.30 | 1.69<br>2.81<br>3.43<br>3.58 | 0.000231<br>.000211<br>.000173<br>.000249 | 33.4<br>45.7<br>52.5<br>43.5 | 0.0446<br>.0383<br>.0350<br>.0430 | *Course*, straight; 502 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 4 E. *Side slopes*, slightly irregular. *Bottom*, fairly regular. *Soil*, dark-colored waxy clay. *Condition*, light growth of weeds on bottom of channel; weeds, weed stubble, and roots on side slopes. *Constructed*, July, 1911. (See Pl. VII, fig. 1; and fig. 3 E.) |

[1] Average maximum depth at bankful stage.

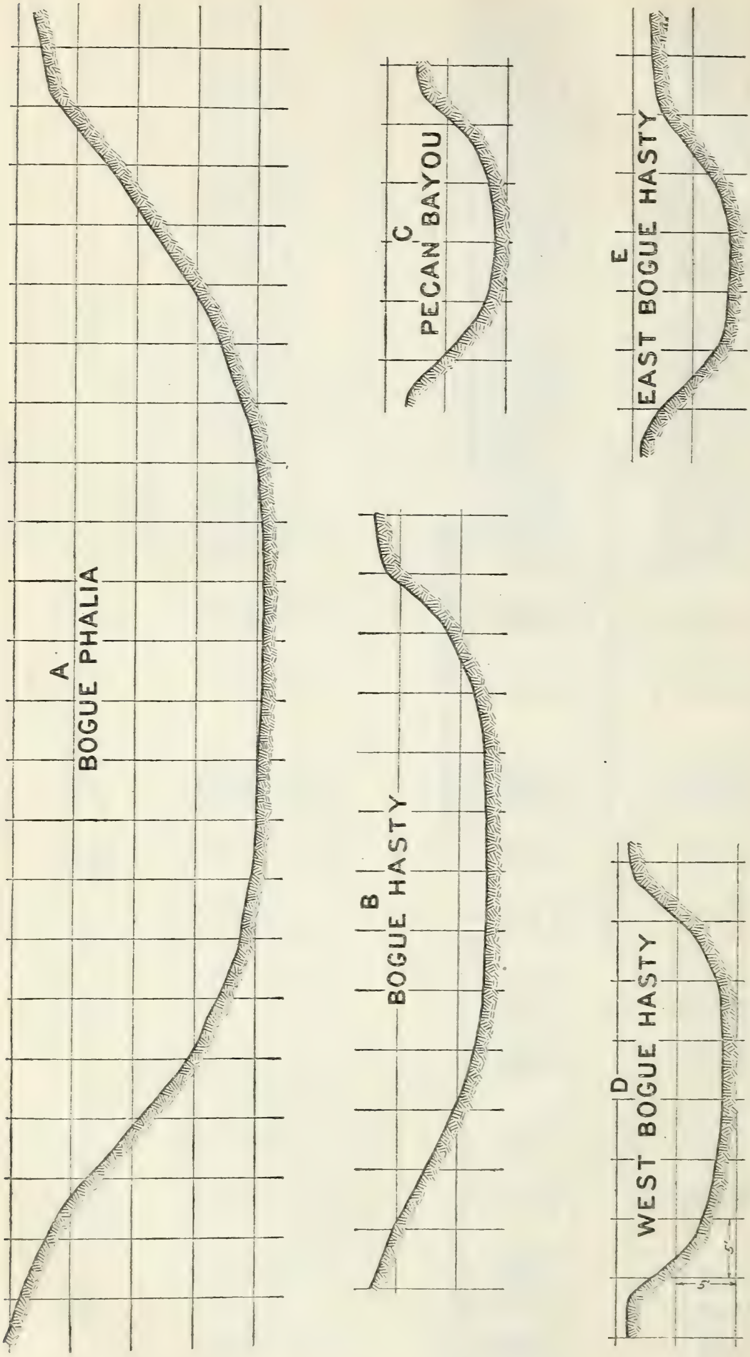


FIG. 3.—Average cross sections of channels for experiments in Bolivar County, Miss.

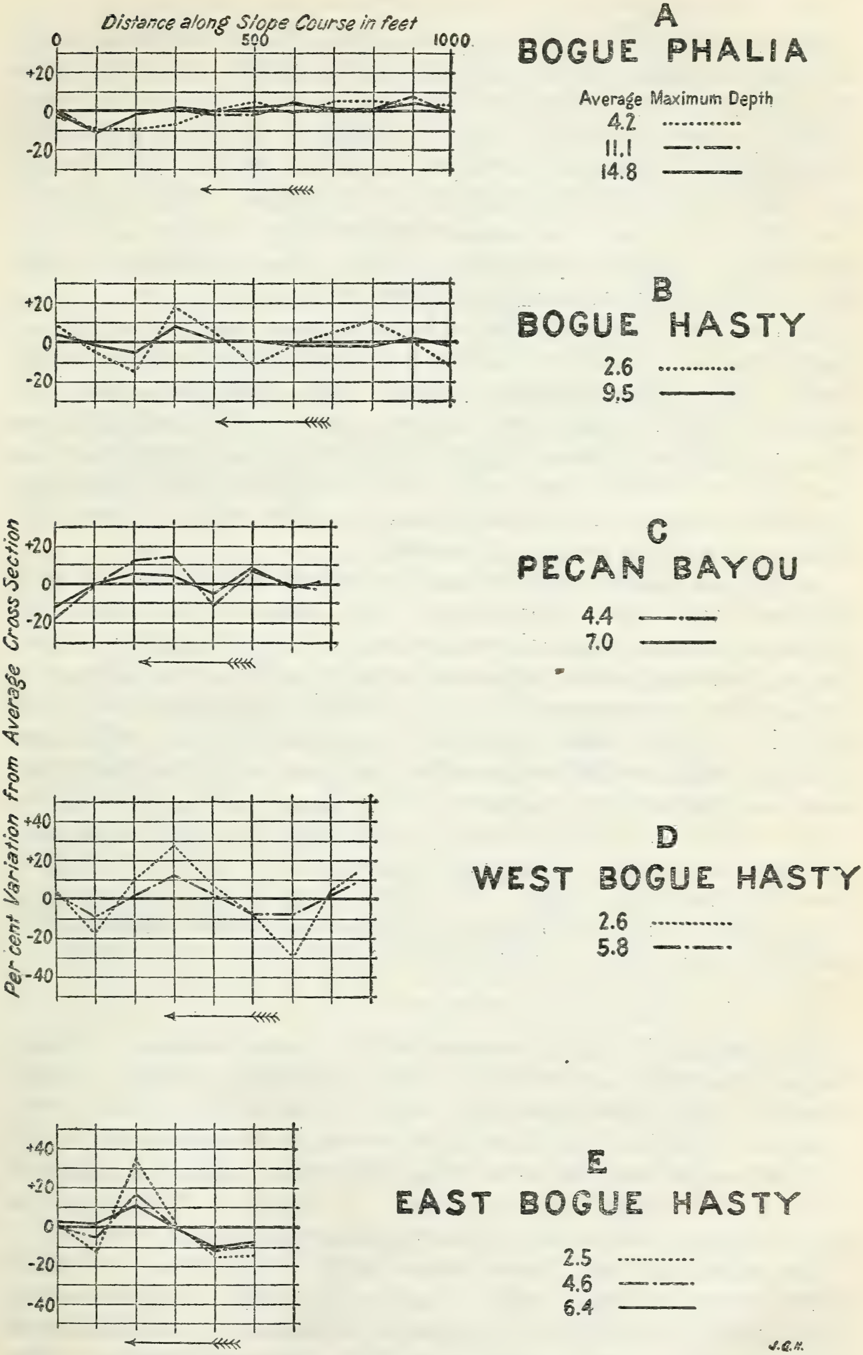


FIG. 4.—Graphs for experiments in Bolivar County, Miss., showing per cent variation from average cross-sectional area for all cross sections along slope courses.

### BOGUE HASTY.

The course used for slope measurements on Bogue Hasty was 1,039 feet long. It was straight and fairly uniform (fig. 4 *B*) and no water through drain tile or surface ditches entered the channel along the course. It was located just above the highway bridge about 3 miles west of Shaw. The lower end of the course was above a slight bend in the channel and about 500 feet above the bridge. The gauging station, which consisted of a suspension footbridge (75-foot span), was placed near the lower end of the course. The conditions for both slope and discharge measurements were very good.

This channel was found not to be in as good condition as that of Bogue Phalia. The right side slope was very irregular and was caving badly. The upper part was covered with weeds and small tree sprouts. The left side slope was very regular and practically free from vegetation. (Plate V, fig. 2.) The soil in the upper part of the channel is a dark silty loam and in the lower part a light-yellow clay. It is sticky when wet and cracks and crumbles when dry (see fig. 3 *B* for average cross section of channel).

Table No. 2 shows the hydraulic elements and the values of $n$ obtained from these experiments. The value of $n$ (0.0382) for extreme low stage is the highest obtained for this ditch, and is probably due to the irregularities in the bed of the channel. The values of $n$ obtained for measurements 11 to 14, inclusive, are applicable to the lower half of the channel, and they agree quite closely with those obtained for Bogue Phalia at bankful stage, the conditions of smoothness and regularity of this part of the channel being very similar to the conditions of the Bogue Phalia channel. The values of $n$ obtained for the higher stages of the channel are considerably higher than for the lower stages. The very irregular and caving right bank would lead one to expect a larger roughness coefficient for bankful stage than for the lower half.

### PECAN BAYOU.

A course 665 feet long was used for slope measurements on Pecan Bayou, located about 600 feet above the highway bridge, 5 miles directly south from Skene and about 3 miles from Shaw. The cross section of the channel at this place was quite uniform (fig. 4 *C*), and no surface water entered along the course, which was situated between two bends in the channel. A suspension footbridge for gauging purposes was placed near the lower end of the course.

Conditions on Pecan Bayou were similar to those described below for West Bogue Hasty. Much water was impounded along the course during periods of no flow. It appears that material was deposited in the channel below to impound water for the purpose of fishing. The side slopes of the channel were very regular. Some weeds were found in the channel, but not nearly as many as in the channel of East Bogue Hasty (Plate VI, fig. 1; and fig. 3 *C*). The soil is a dark-colored clay, which cracks and crumbles when dry. The slope of the water surface was found to be exceedingly small, much less than the grades designated in the original design of the channel. This was due, no doubt, to the amount of sediment deposited in the channel below the course. The values of *n* obtained are shown in Table 2.

### WEST BOGUE HASTY.

For slope measurements on this channel a straight course 757 feet long, of quite uniform cross section at bankful stage (fig. 4 *D*), was selected, located north of the highway bridge, about 1 mile east of Litton and about 6 miles from Shaw. At the lower end of the course, stakes for slope measurements were located about 50 feet above the entrance of a lateral surface ditch. The gaugings for discharge were made from a suspension footbridge built about in the middle of the course.

The collection of drift by the bridge below the course and sedimentary deposits as a result of the drift and the entrance of a lateral ditch just above the bridge rendered this course rather unsuitable for accurate determinations of the value of *n*. During periods of no flow a pond of stagnant water extended nearly the whole length of the course, this being due to the sediment deposited near the bridge. The side slopes and bed of the channel were quite regular. Some weeds were found on the side slopes (Plate VI, fig. 2). The soil is similar to that found in the channel of Bogue Hasty (see fig. 3 *D* for average cross section). The results of the experiments on this ditch are shown in Table 2.

### EAST BOGUE HASTY.

The course for slope measurements on East Bogue Hasty was established above the highway bridge, about 2 miles east of Litton and about 5 miles from Shaw. A stretch of 502 feet was selected, its upper end being just below a curve in the channel and the lower end just above the bridge and the entrance of a lateral ditch. The discharge measurements were made from a suspension footbridge about midway of the course. This course was rather short for accurate determinations of slope but was the straightest stretch of comparatively uniform section (fig. 4 *E*) that could be found near the lower end of the channel.

The side slopes, and in some places the bed of the channel, were covered with weeds and weed stubble, and the side slopes were slightly irregular (Plate VII, fig. 1). Practically no caving took place along the course, which fact was due, no doubt, to the vegetation covering the banks. The soil is quite similar to that in the channel of Pecan Bayou.

The values obtained for $n$ are shown in Table 2, and, as would be expected from the condition of the channel, are even higher than those found for a bankful stage of Bogue Hasty. Some trouble was experienced during the measurements, due to drift collected at the bridge, and this may be in part responsible for the rather high values obtained for $n$. (See fig. 3 *E* for average cross section.)

### DISCUSSION OF BOLIVAR COUNTY EXPERIMENTS.

From the foregoing description of the results obtained and the conditions existing in each of the canals it is apparent that the most dependable data were obtained for the Bogue Phalia and Bogue Hasty channels. These results show that a value of $n$ of about 0.030, or slightly larger, applies to channels similar to the whole channel of Bogue Phalia.

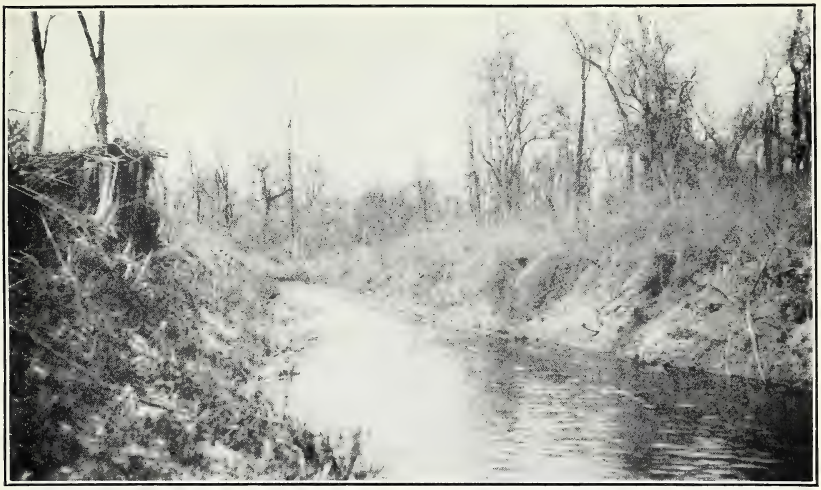
The values obtained for the whole channel of Bogue Hasty, Pecan Bayou, and East and West Bogue Hasty demonstrate the effect of the conditions described upon the value of $n$. These values can be used as a guide in the design of drainage channels where like conditions can reasonably be expected to exist, due to the lack of maintenance of the channels or to the caving in of the banks. These data ought also to serve a useful purpose in estimating the discharge of old channels where like conditions prevail.

## EXPERIMENTS IN WESTERN TENNESSEE.

These experiments were conducted during the years 1916 and 1917. Values of $n$ were obtained for six different courses of the channel of the South Forked Deer River and for courses of the channels of the North Forked Deer River, Huggins Creek, Sugar Creek, and Cypress Creek. The author was assisted in these experiments by H. S. Andrews and A. L. Lane, junior drainage engineers of the bureau.

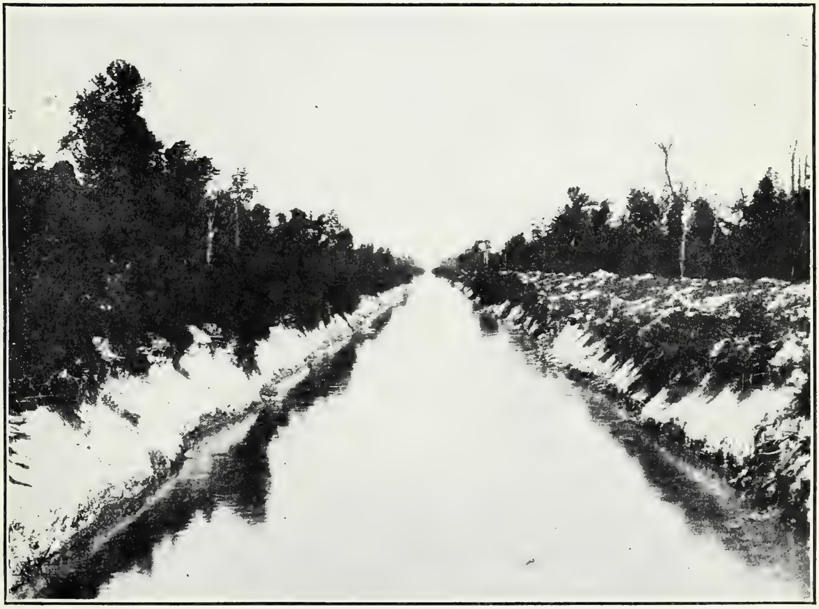
### SOUTH FORKED DEER RIVER NEAR ROBERTS.

Gaugings of this channel were made from a single-span highway bridge about 1 mile south of Roberts. The slope course was 1,412 feet long, and was located just above the gauging station. The channel increased gradually in size from the upper to the lower end of the course, there being no abrupt changes in size or shape along the course (figs. 5 *A*, and 6 *A*). There was no vegetation nor any marked irregularities in the channel (Plate VII, fig. 2). Considerable erosion had taken place in this channel to which was largely due, no doubt, the remarkably few irregularities and the freedom from vegetation. As shown in Table 3, lower values of $n$ were obtained for this channel than for any of the other channels in Tennessee.



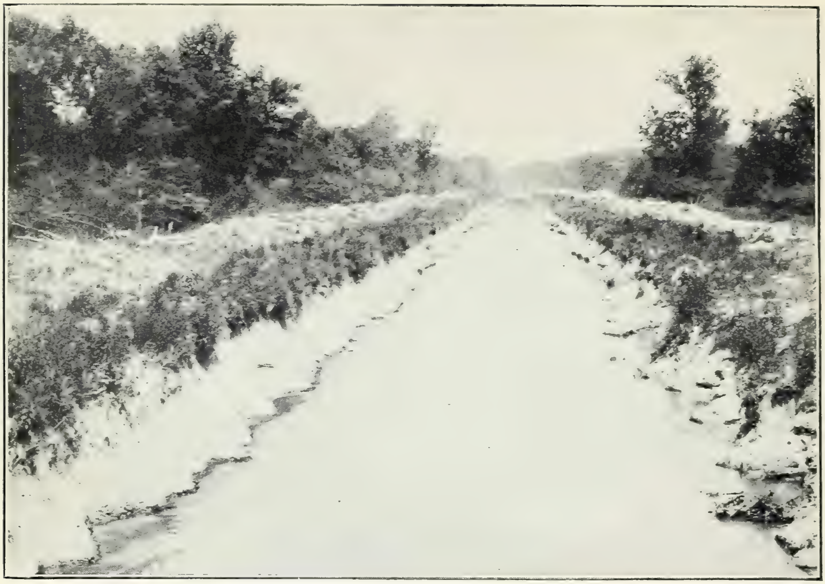
B. P. R.—D410

FIG. 1.—SLOPE COURSE OF EAST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS., 1915. (SEE TABLE NO. 2.)



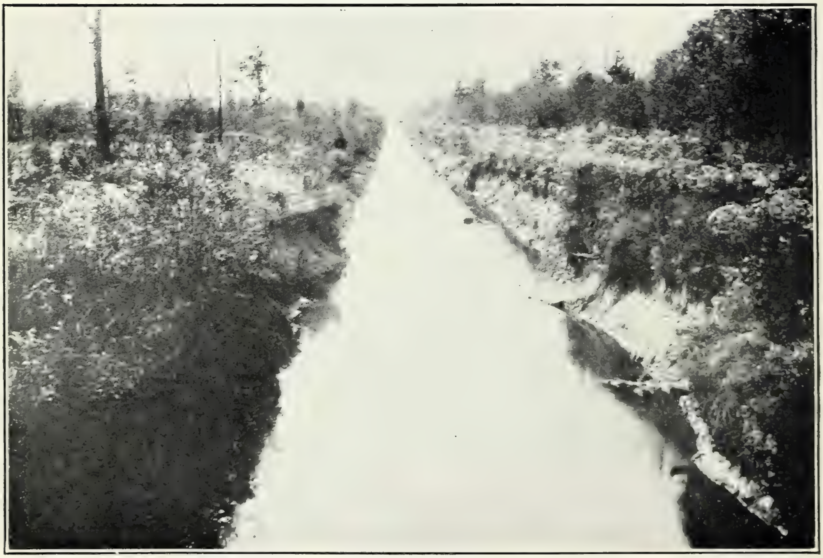
B. P. R.—D1285

FIG. 2.—SLOPE COURSE OF SOUTH FORKED DEER RIVER DREDGED CHANNEL, NEAR ROBERTS, TENN., 1916. (SEE TABLE NO. 3.)



B. P. R.—D1287

FIG. 1.—SLOPE COURSE OF SOUTH FORKED DEER RIVER DREDGED CHANNEL AT BOLIVAR LEVEE ROAD, NEAR JACKSON, TENN., 1917. (SEE TABLE NO. 3.)



B. P. R.—D1381

FIG. 2.—SLOPE COURSE OF SOUTH FORKED DEER RIVER DREDGED CHANNEL, NEAR HENDERSON, TENN., 1916. (SEE TABLE NO. 3.)

TABLE 3.—*Results of experiments made in western Tennessee.*

SOUTH FORKED DEER RIVER DREDGED CHANNEL, NEAR ROBERTS, TENN.

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ *C.* | Coefficient of roughness *n.* | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Feet.* | *Feet.* | *Second-feet.* | *Sq. ft.* | *Ft. per sec.* | *Feet.* | | | | |
| 1 | Feb. 26, 1916 | 7.7 | 51.0 | 614.3 | 328.4 | 1.87 | 5.76 | 0.000094 | 80.5 | 0.0255 | *Course*, straight; 1,412 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 6 A. *Side slopes*, regular and smooth. *Bottom*, even and fairly smooth. *Soil*, lower part, hard clay; upper part, clay loam. *Condition*, no vegetation or obstructions of any sort in channel. *Constructed*, October, 1915. (See Pl. VII, fig. 2; and fig. 5A.) |
| 2 | Feb. 10, 1916 | 8.9 | 52.4 | 798.2 | 390.0 | 2.04 | 6.50 | .000094 | 82.6 | .0254 | |
| 3 | Mar. 29, 1916 | 9.5 | 53.4 | 919.4 | 421.8 | 2.18 | 6.84 | .000096 | 85.2 | .0252 | |
| 4 | Apr. 4, 1916 | 10.3 | 54.5 | 1,252.1 | 465.0 | 2.70 | 7.28 | .000124 | 90.0 | .0240 | |
| 5 | Mar. 4, 1916 | 10.8 | 55.2 | 1,502.6 | 494.0 | 3.04 | 7.55 | .000166 | 86.0 | .0248 | |
| | .............. | [1] 13.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |

SOUTH FORKED DEER RIVER DREDGED CHANNEL AT BOLIVAR ROAD, NEAR JACKSON, TENN.

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ *C.* | Coefficient of roughness *n.* | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | Dec. 13, 1916 | 4.3 | 37.6 | 191.6 | 115.9 | 1.66 | 2.89 | 0.000530 | 42.4 | 0.0420 | *Course*, straight; 952 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 6 B. *Side slopes*, fairly regular near top, but extremely irregular and uneven near bottom. *Bottom*, very uneven and full of holes. *Soil*, heavy clay loam. *Condition*, no vegetation or obstructions in channel. *Constructed*, March, 1916. *General remarks*, high values of *n* are due to very rough and irregular condition of channel as originally dredged. The upper portion of channel is fairly regular. (See Pl. VIII, fig. 1; and fig. 5B.) |
| 7 | Dec. 20, 1916 | 4.95 | 38.4 | 282.2 | 143.0 | 1.97 | 3.33 | .000555 | 45.8 | .0402 | |
| 8 | Dec. 22, 1916 | 5.0 | 38.5 | 290.4 | 147.0 | 1.98 | 3.40 | .000562 | 45.3 | .0401 | |
| 9 | Mar. 31, 1917 | 5.1 | 38.6 | 375.0 | 150.0 | 2.50 | 3.46 | .000694 | 51.2 | .0362 | |
| 10 | Feb. 21, 1917 | 5.5 | 39.2 | 433.0 | 166.0 | 2.61 | 3.69 | .000630 | 54.2 | .0348 | |
| 11 | Jan. 17, 1917 | 5.8 | 39.6 | 477.0 | 178.0 | 2.68 | 3.87 | .000642 | 53.8 | .0349 | |
| 12 | Dec. 28, 1916 | 9.3 | 51.6 | 1,078.0 | 344.0 | 3.13 | 5.69 | .000477 | 60.2 | .0341 | |
| 13 | Jan. 31, 1917 | 9.8 | 54.0 | 1,296.0 | 366.0 | 3.55 | 5.83 | .000534 | 63.6 | .0322 | |
| 14 | Jan. 6, 1917 | 10.4 | 57.1 | 1,362.0 | 399.4 | 3.41 | 6.10 | .000436 | 66.1 | .0310 | |
| | .............. | [1] 11.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |

SOUTH FORKED DEER RIVER DREDGED CHANNEL, NEAR HENDERSON, TENN., 1916.

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ *C.* | Coefficient of roughness *n.* | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | Mar. 30, 1916 | 3.2 | 26.1 | 115.2 | 73.3 | 1.57 | 2.46 | 0.000257 | 62.4 | 0.0275 | *Course*, straight; 624 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 6 C. *Side slopes*, slightly irregular. *Bottom*, fairly regular; uneven in places with small depressions. *Soil*, heavy clay near bottom; clay loam near top. *Condition*, practically no vegetation in channel. *Constructed*, November, 1914. (See Pl. VIII, fig. 2; and fig. 5C.) |
| 16 | Mar. 1, 1916 | 3.8 | 27.1 | 169.4 | 89.0 | 1.90 | 2.81 | .000393 | 57.2 | .0307 | |
| 17 | May 16, 1916 | 3.9 | 27.4 | 193.2 | 91.5 | 2.11 | 2.87 | .000305 | 71.3 | .0249 | |
| 18 | May 22, 1916 | 5.8 | 30.4 | 358.0 | 147.0 | 2.43 | 3.96 | .000361 | 64.4 | .0294 | |
| 19 | May 3, 1916 | 6.4 | 31.5 | 434.6 | 168.3 | 2.58 | 4.34 | .000345 | 66.8 | .0290 | |
| | .............. | [1] 9.3 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |

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[1] Average maximum depth at bankful stage.

TABLE 3.—*Results of experiments made in western Tennessee*—Continued.

SOUTH FORKED DEER RIVER DREDGED CHANNEL, NEAR HENDERSON, TENN., 1917.

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ $C$. | Coefficient of roughness $n$. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Feet.* | *Feet.* | *Second-feet.* | *Sq. ft.* | *Ft. per sec.* | *Feet.* | | | | |
| 20 | Feb. 23, 1917 | 4.1 | 29.5 | 224.1 | 100.0 | 2.24 | 3.11 | 0.000532 | 55.0 | 0.0329 | *Course*, same as above. *Cross section*, very little variation in shape; for variation in size, see fig. 6 D. *Condition*, channel in practically the same condition as described above, but slightly enlarged due to caving and erosion. |
| 21 | Jan. 4, 1917 | 4.2 | 29.6 | 240.8 | 103.0 | 2.34 | 3.17 | .000486 | 59.6 | .0301 | |
| 22 | Jan. 20, 1917 | 4.3 | 29.7 | 260.9 | 106.0 | 2.46 | 3.24 | .000435 | 65.6 | .0277 | |
| 23 | Jan. 23, 1917 | 5.3 | 31.3 | 333.9 | 138.0 | 2.42 | 3.89 | .000314 | 69.2 | .0272 | |
| 24 | Feb. 15, 1917 | 6.1 | 32.7 | 423.9 | 164.0 | 2.58 | 4.34 | .000313 | 70.0 | .0275 | |
| 25 | Jan. 6, 1917 | [1] 9.3 | 36.6 | 953.1 | 278.9 | 3.44 | 6.04 | .000332 | 76.8 | .0268 | |

NORTH FORKED DEER RIVER DREDGED CHANNEL, NEAR TRENTON, TENN., 1916.

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ $C$. | Coefficient of roughness $n$. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | Feb. 4, 1916 | 3.6 | 26.5 | 37.6 | 49.2 | 0.76 | 1.93 | 0.000106 | 53.2 | 0.0295 | *Course*, straight; 699 feet long. *Cross section*, very little variation in shape. for variation in size, see fig. 6 E. *Side slopes*, fairly regular, smooth, and steep. *Bottom*, rather irregular. *Soil*, clay loam. *Condition*, no vegetation or obstructions, banks caving badly. *Constructed*, May, 1915. (See Pl. IX, fig. 1.) |
| 27 | May 4, 1916 | 3.8 | 27.3 | 59.4 | 55.0 | 1.08 | 2.08 | .000126 | 66.8 | .0243 | |
| 28 | May 15, 1916 | 10.7 | 40.3 | 1,167.0 | 316.0 | 3.69 | 6.22 | .000382 | 75.6 | .0271 | |
| | .............. | [1] 11.0 | ........ | .......... | ........ | ........ | ........ | .......... | .......... | ........ | |

NORTH FORKED DEER RIVER DREDGED CHANNEL, NEAR TRENTON, TENN., 1917.

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ $C$. | Coefficient of roughness $n$. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | July 22, 1917 | 2.5 | 28.8 | 76.1 | 50.0 | 1.52 | 1.64 | 0.000332 | 65.2 | 0.0240 | *Course*, same as above. *Cross section*, very little variation in shape; for variations in size, see fig. 6 F. *Condition*, very similar to that described above except that the size has increased greatly due to erosion and caving of banks. (See fig. 5 D for cross section.) |
| 30 | Apr. 9, 1917 | 3.1 | 30.5 | 125.8 | 69.2 | 1.82 | 2.12 | .000361 | 65.7 | .0253 | |
| 31 | July 24, 1917 | 3.4 | 31.8 | 189.3 | 81.0 | 2.34 | 2.38 | .000450 | 71.6 | .0243 | |
| 32 | .....do....... | 3.9 | 33.4 | 246.0 | 97.0 | 2.54 | 2.70 | .000432 | 74.2 | .0239 | |
| 33 | .....do....... | 4.9 | 36.8 | 381.8 | 134.0 | 2.85 | 3.34 | .000427 | 75.6 | .0243 | |
| 34 | July 23, 1917 | 8.9 | 47.8 | 1,257.5 | 305.0 | 4.12 | 5.54 | .000468 | 81.0 | .0249 | |
| 35 | .....do....... | 9.1 | 48.0 | 1,317.0 | 313.0 | 4.21 | 5.64 | .000507 | 78.8 | .0255 | |
| 36 | .....do....... | 9.2 | 48.2 | 1,324.0 | 318.0 | 4.16 | 5.70 | .000520 | 76.4 | .0265 | |
| 37 | Jan. 5, 1917 | 10.5 | 48.8 | 1,513.0 | 367.3 | 4.12 | 6.39 | .000444 | 77.3 | .0267 | |
| | .............. | [1] 11.0 | ........ | .......... | ........ | ........ | ........ | .......... | .......... | ........ | |

[1] Average maximum depth at bankful stage.

HUGGINS CREEK DREDGED CHANNEL, NEAR FINGER, TENN., 1916.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 38 | May 22, 1916 | 1.8 | 18.1 | 50.7 | 32.7 | 1.55 | 1.56 | 0.000855 | 42.5 | 0.0352 | *Course*, straight; 914 feet long. *Cross section*, rather abrupt variations in shape; for variation in size, see fig. 6 G. *Side slopes*, very irregular. *Bottom*, rather smooth and even. *Soil*, clay loam containing some sand. *Condition*, growth of grass, weeds, and small sprouts in channel; considerable caving of banks. *Constructed* Oct., 1914. (See fig. 5 E.) |
| 39 | Feb. 9, 1916 | 1.85 | 18.3 | 54.1 | 34.0 | 1.60 | 1.62 | .000923 | 41.4 | .0369 | |
| 40 | Apr. 3, 1916 | 2.0 | 19.0 | 63.3 | 36.6 | 1.73 | 1.71 | .000824 | 46.2 | .0340 | |
| 41 | Feb. 1, 1916 | 3.0 | 21.0 | 97.4 | 51.0 | 1.91 | 2.16 | .000875 | 43.9 | .0371 | |
| 42 | May 30, 1916 | 4.0 | 23.0 | 159.5 | 74.2 | 2.15 | 2.75 | .000564 | 54.5 | .0322 | |
| 43 | ......do....... | [1]6.3 | 31.0 | 371.8 | 140.4 | 2.65 | 3.64 | .000620 | 55.8 | .0333 | |

HUGGINS CREEK DREDGED CHANNEL, NEAR FINGER, TENN., 1916–17.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 44 | Dec. 8, 1916 | 2.0 | 18.9 | 49.1 | 35.4 | 1.39 | 1.72 | 0.000738 | 38.9 | 0.0398 | *Course*, straight; 618 feet long; part of 1916 course. *Condition*, channel in considerably worse condition than when first series of measurements were made; more irregular and rough due to caving banks and a great deal more vegetation in channel. (See Pl. IX, fig. 2; and fig. 6 H.) |
| 45 | .....do....... | 2.3 | 19.6 | 63.2 | 40.5 | 1.56 | 1.87 | .000713 | 42.6 | .0373 | |
| 46 | Dec. 28, 1916 | 2.55 | 20.1 | 88.2 | 46.0 | 1.92 | 2.06 | .000888 | 44.8 | .0366 | |
| 47 | Feb. 15, 1917 | 2.60 | 20.2 | 88.4 | 47.0 | 1.88 | 2.09 | .000834 | 45.1 | .0363 | |
| 48 | Dec. 28, 1916 | 3.0 | 20.8 | 115.2 | 55.9 | 2.06 | 2.34 | .000835 | 46.6 | .0362 | |
| 49 | Jan. 13, 1917 | 3.2 | 21.1 | 123.6 | 58.8 | 2.10 | 2.42 | .000832 | 46.9 | .0362 | |
| 50 | Mar. 3, 1917 | 3.5 | 22.2 | 143.6 | 64.3 | 2.23 | 2.55 | .000877 | 47.2 | .0365 | |
| | ................ | [1]6.3 | ........ | .......... | ........ | ........ | ........ | .......... | ........ | ........ | |

SUGAR CREEK DREDGED CHANNEL, NEAR HENDERSON, TENN.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | Mar. 29, 1917 | 1.9 | 17.3 | 23.1 | 25.4 | 0.91 | 1.37 | 0.000729 | 28.8 | 0.0495 | *Course*, 669 feet long; first half straight, last half curved. *Cross section*, very little variation in shape; for variations in size, see fig. 6 I. *Side slopes*, upper part, smooth and regular; lower part, rather rough. *Bottom*, very rough and irregular with numerous holes. *Soil*, stiff clay loam; does not wash easily. *Condition*, some roots extending from sides of channel; very little vegetation in channel. *Constructed*, Dec., 1915. *Remarks*, very rough condition of bottom is mainly responsible for high values of *n* obtained. (See Pl. X, fig. 1; and fig. 5 F.) |
| 52 | Mar. 27, 1917 | 2.1 | 17.5 | 29.8 | 29.2 | 1.02 | 1.53 | .000825 | 28.8 | .0500 | |
| 53 | Jan. 4, 1917 | 2.6 | 18.2 | 63.6 | 39.9 | 1.59 | 1.96 | .000970 | 36.5 | .0437 | |
| 54 | Feb. 15, 1917 | 3.5 | 19.4 | 148.0 | 57.8 | 2.56 | 2.57 | .001232 | 45.5 | .0378 | |
| 55 | Dec. 28, 1917 | 6.3 | 27.2 | 322.0 | 116.0 | 2.78 | 3.41 | .000936 | 49.2 | .0373 | |
| 56 | Jan. 29, 1917 | 6.4 | 27.4 | 376.2 | 117.5 | 3.20 | 3.42 | .001111 | 51.8 | .0357 | |
| 57 | Jan. 22, 1917 | 6.6 | 28.2 | 355.2 | 121.9 | 2.92 | 3.44 | .000920 | 51.9 | .0356 | |
| 58 | July 26, 1917 | 6.9 | 29.2 | 347.2 | 128.0 | 2.71 | 3.49 | .000738 | 53.5 | .0345 | |
| 59 | Jan. 5, 1917 | [1]7.1 | 29.9 | 406.5 | 132.2 | 3.08 | 3.51 | .000855 | 56.1 | .0331 | |

CYPRESS CREEK, DREDGED CHANNEL, NEAR BETHEL SPRINGS, TENN.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | Feb. 15, 1917 | 0.7 | 12.5 | 7.9 | 8.9 | 0.89 | 0.67 | 0.002080 | 23.9 | 0.0470 | *Course*, straight; 308 feet long. *Cross section*, abrupt variations in shape; for variation in size, see fig. 6 J. *Side slopes*, very irregular and rough. *Bottom*, uneven; subject to variation due to sand deposits. *Soil*, clay loam. *Condition*, exposed perimeter above low water practically covered with grass and weeds. *Constructed*, December, 1915. (See Pl. X, fig. 2; and fig. 5 G.) |
| 61 | July 23, 1917 | 2.3 | 17.3 | 72.4 | 33.8 | 2.14 | 1.76 | .002435 | 32.7 | .0470 | |
| 62 | .....do....... | 2.9 | 18.8 | 103.7 | 42.1 | 2.46 | 1.99 | .001915 | 39.9 | .0403 | |
| | ................ | [1]5.5 | ........ | .......... | ........ | ........ | ........ | .......... | ........ | ........ | |

[1] Average maximum depth at bankful stage.

TABLE 3.—*Results of experiments made in western Tennessee*—Continued.

SOUTH FORKED DEER RIVER, OLD AND DREDGED CHANNELS, AT CAMPBELLS LEVEE ROAD, NEAR JACKSON, TENN.

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ *C.* | Coefficient of roughness *n.* | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Feet.* | *Feet.* | *Second-feet.* | *Sq. ft.* | *Ft. per sec.* | *Feet.* | | | | |
| | IRREGULAR DREDGED CHANNEL. | | | | | | | | | | |
| 63 | Mar. 20, 1916 | 4.5 | 43.6 | 395.2 | 176.1 | 2.24 | 3.61 | 0.000571 | 49.4 | 0.0380 | *Course*, fairly straight; 534 feet long. *Cross section*, rather gradual variations in shape; for variation in size, see fig. 6 K. *Side slopes*, very irregular. *Bottom*, very rough and uneven. *Soil*, sandy clay loam. *Condition*, very little vegetation; few obstructions in channel. *Constructed*, August, 1914 (See Pl. XI, fig. 1; and fig. 5 H.) |
| 64 | Feb. 25, 1916 | 6.1 | 46.9 | 545.9 | 249.0 | 2.19 | 4.65 | .000552 | 43.2 | .0455 | |
| 65 | Mar. 29, 1916 | 7.3 | 49.8 | 735.7 | 305.0 | 2.41 | 5.33 | .000452 | 49.2 | .0410 | |
| 66 | Mar. 4, 1916 | 7.5 | 50.3 | 715.1 | 315.6 | 2.27 | 5.45 | .000300 | 56.2 | .0367 | |
| | .............. | [1] 13.0 | ........ | .......... | ........ | ........ | ........ | ............ | .......... | ........ | |
| | OLD STRAIGHT RIVER CHANNEL. | | | | | | | | | | |
| 67 | Mar. 20, 1916 | 7.0 | 40.0 | 395.2 | 196.2 | 2.01 | 4.44 | 0.000584 | 39.5 | 0.0500 | *Course*, fairly straight; 497 feet long. *Cross section*, considerable variation in shape; for variation in size, see fig. 6 L. *Side slopes*, irregular. *Bottom*, irregular with deep holes. *Soil*, sandy clay loam. *Condition*, sides of channel covered with trees, roots, and vines and subject to caving; logs, branches, and other drift on bottom of channel. (See Pl. XI, fig. 2; and fig. 5 I.) |
| 68 | Feb. 25, 1916 | 8.0 | 41.7 | 545.9 | 240.2 | 2.27 | 5.09 | .000734 | 37.2 | 0550 | |
| 69 | Mar. 29, 1916 | 8.8 | 43.2 | 735.7 | 275.0 | 2.68 | 5.56 | .001088 | 34.4 | .0620 | |
| 70 | Mar. 4, 1916 | 8.9 | 43.7 | 715.1 | 281.9 | 2.54 | 5.66 | .000952 | 34.6 | .0619 | |
| 71 | Feb. 3, 1916 | 11.5 | 48.8 | 1,066.6 | 403.2 | 2.64 | 7.19 | .000501 | 44.1 | .0505 | |
| | .............. | [1] 13.5 | ........ | .......... | ........ | ........ | ........ | ............ | .......... | ........ | |
| | OLD CROOKED RIVER CHANNEL. | | | | | | | | | | |
| 72 | Mar. 20, 1916 | 5.1 | 46.5 | 395.2 | 241.2 | 1.64 | 4.15 | 0.003773 | 13.1 | 0.1520 | *Course*, very crooked, containing four distinct curves; 705 feet long at low water. *Cross section*, large variations in shape; for variation in size, see fig. 6 M. *Side slopes*, very irregular. *Bottom*, very irregular and full of holes. *Soil*, sandy clay loam. *Condition*, many roots, trees, and bushes on sides, and many logs, large trees, and other drift on bottom; trees are continually falling into channel, due to caving banks. (See Pl. XII, fig. 1; and fig. 5 J.) |
| 73 | Feb. 25, 1916 | 6.5 | 50.0 | 545.9 | 311.5 | 1.75 | 4.99 | .003812 | 12.7 | .1620 | |
| 74 | Mar. 29, 1916 | 7.6 | 54.0 | 735.7 | 366.0 | 2.01 | 5.56 | .003450 | 14.6 | .1500 | |
| 75 | Mar. 4, 1916 | 7.8 | 55.0 | 715.1 | 376.7 | 1.99 | 5.68 | .002709 | 15.3 | .1460 | |
| 76 | Feb. 3, 1916 | 11.1 | 64.5 | 1,066.6 | 575.8 | 1.85 | 7.60 | .001486 | 17.4 | .1400 | |
| | .............. | [1] 13.0 | ........ | .......... | ........ | ........ | ........ | ............ | .......... | ........ | |

---

[1] Average maximum depth at bankful stage.

### SOUTH FORKED DEER RIVER NEAR JACKSON.

Discharge measurements of this channel were made from a single-span skew highway bridge on the Bolivar levee road about one-half mile from Jackson. The upper end of the slope course was located about 75 feet below the bridge and extended downstream 952 feet in a straight course. The cross-sectional area was fairly uniform for high stages, but for low stages several abrupt changes in size occurred (figs. 5 *B*, and 6 *B*). The effect of roughness and irregularities in the lower portion of the channel upon the value of *n* is revealed in the results obtained (Table 3). Although the channel was free from vegetation and obstructions, yet the values of *n* obtained are considerably higher than those obtained for the channel at Roberts. The irregularities in the channel were left at the time of construction, the bottoms and sides having never been smoothed up properly (see Plate VIII, fig. 1).

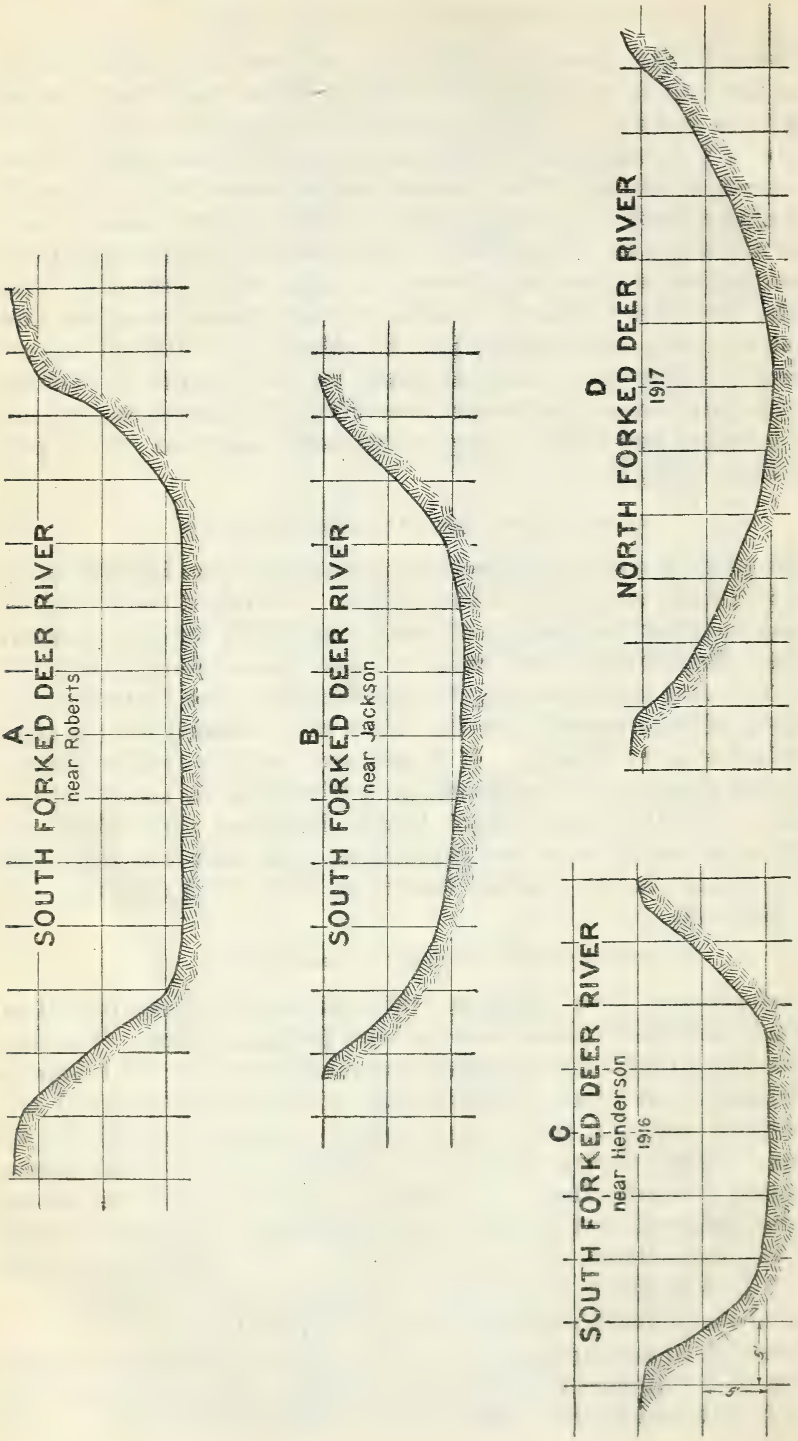
### SOUTH FORKED DEER RIVER NEAR HENDERSON.

The gauging station was located on the single-span highway bridge about 1½ miles east of Henderson, Tenn. A straight course 624 feet in length, below the gauging station, was selected for slope measurements. Experiments were made on this channel during both 1916 and 1917, and there was very little difference in the channel for the two sets of experiments or in the values of *n* obtained for the corresponding stages (Table 3). It is believed that the results obtained are quite accurate. The channel as a whole was in very good condition. The side slopes were slightly irregular, the bottom was fairly even except for a few depressions, and there was practically no vegetation in the channel (see Plate VIII, fig. 2; and figs. 5 *C*, 6 *C*, and 6 *D*).

### NORTH FORKED DEER RIVER NEAR TRENTON.

A single-span skew bridge on the Huntingdon levee road about one-half mile from Trenton was used as a gauging station. The slope course was straight and extended upstream from near the bridge for a distance of 699 feet. The variations in the cross-sectional area were quite large, but there were no abrupt changes in section for the higher stages. Owing to the fact that the size of the channel increased gradually from the upper to the lower end of the course, it is not believed that the differences in the area of the cross section had any appreciable effect upon the value of *n* for the course (see figs. 5 *D*, 6 *E*, and 6 *F*). There were practically no vegetation or other obstructions in the channel (Plate IX, fig. 1).

Referring to measurements 28 and 37 in Table 3, it is seen that the values of *n* obtained for the highest stages during 1916 and 1917 were 0.0271 and 0.0267, respectively. The increase in size of the


A
SOUTH FORKED DEER RIVER
near Roberts
B
SOUTH FORKED DEER RIVER
near Jackson
C
SOUTH FORKED DEER RIVER
near Henderson
1916
5'
5'
D
NORTH FORKED DEER RIVER
1917

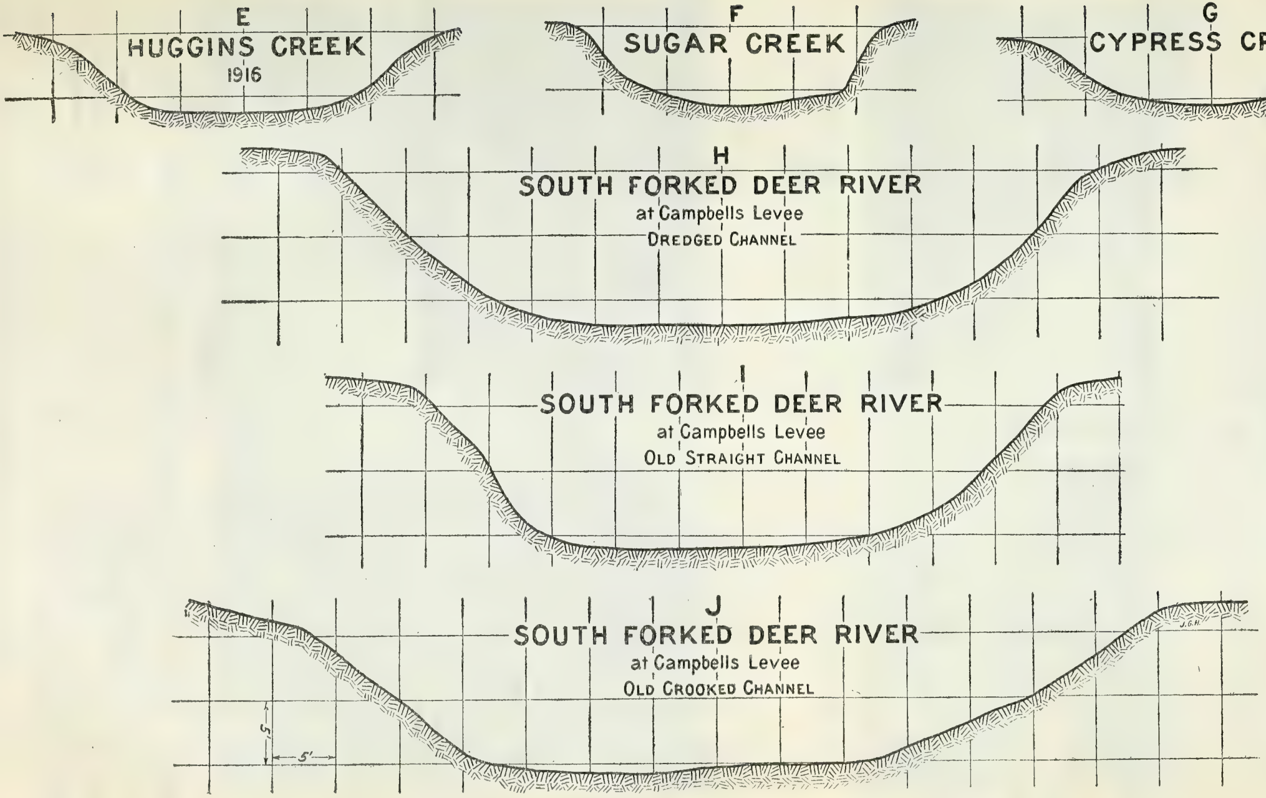


FIG. 5.—Average cross sections of channels for experiments in western Tennessee.

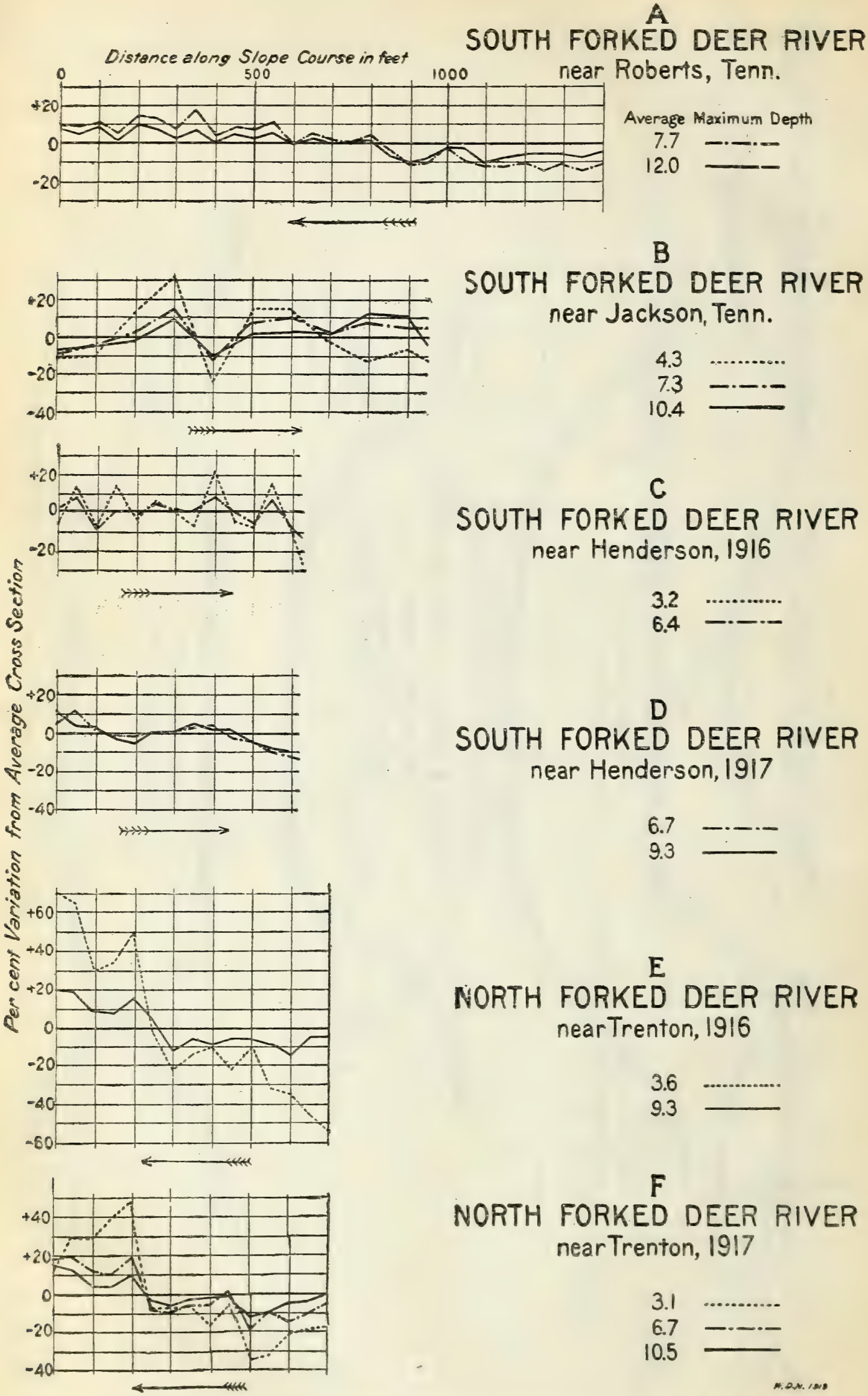
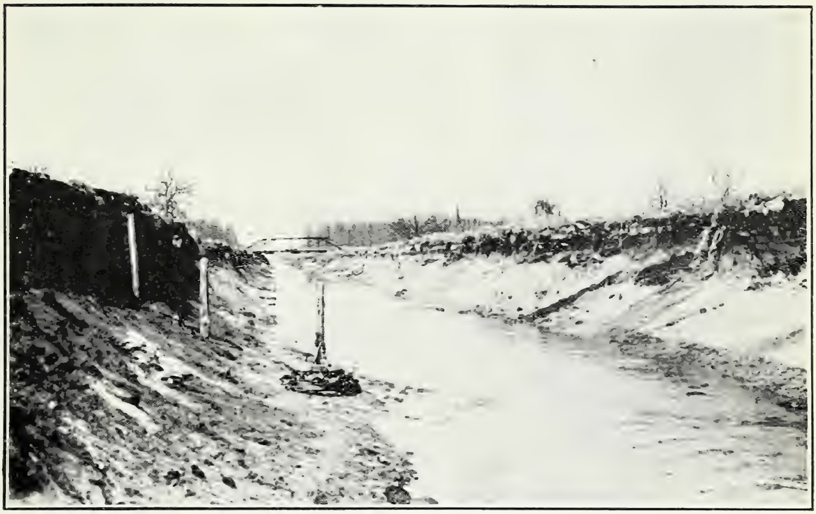
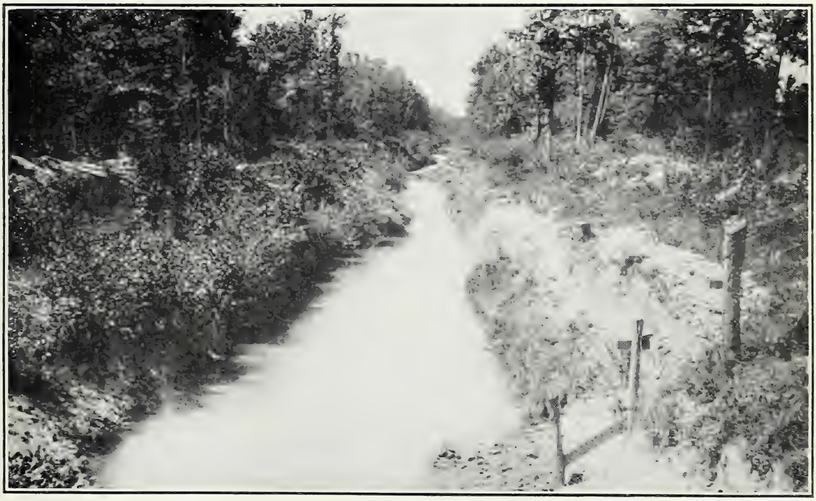


FIG. 6.—Graphs for experiments in western Tennessee, showing per cent variation



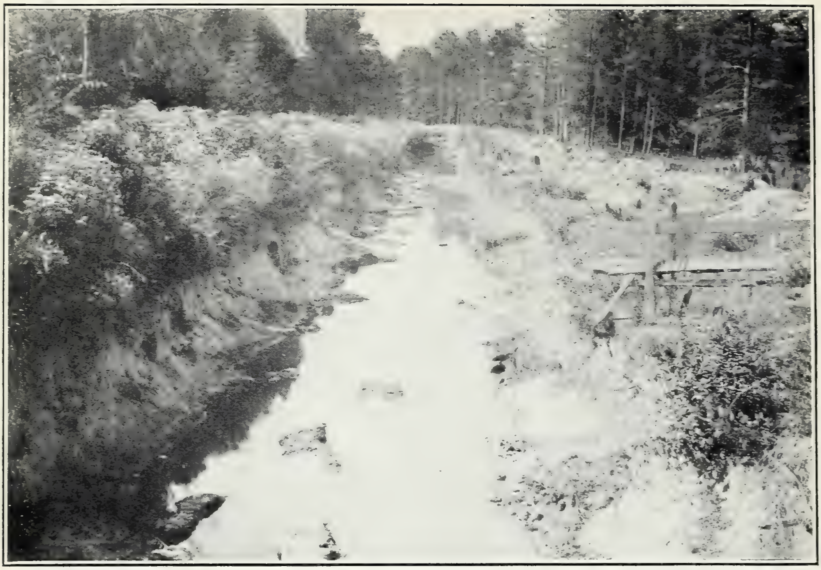
B. P. R.–D272

FIG. 1.—SLOPE COURSE OF NORTH FORKED DEER RIVER DREDGED CHANNEL, NEAR TRENTON, TENN., 1916. (SEE TABLE NO. 3.)



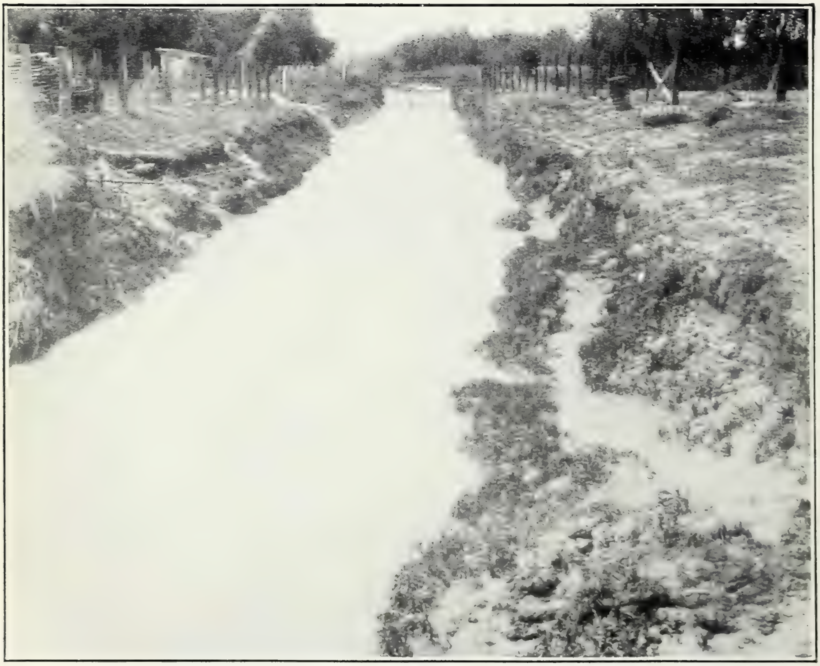
B. P. R.–D1797

FIG. 2.—SLOPE COURSE OF HUGGINS CREEK DREDGED CHANNEL, NEAR FINGER, TENN., 1917. (SEE TABLE NO. 3.)



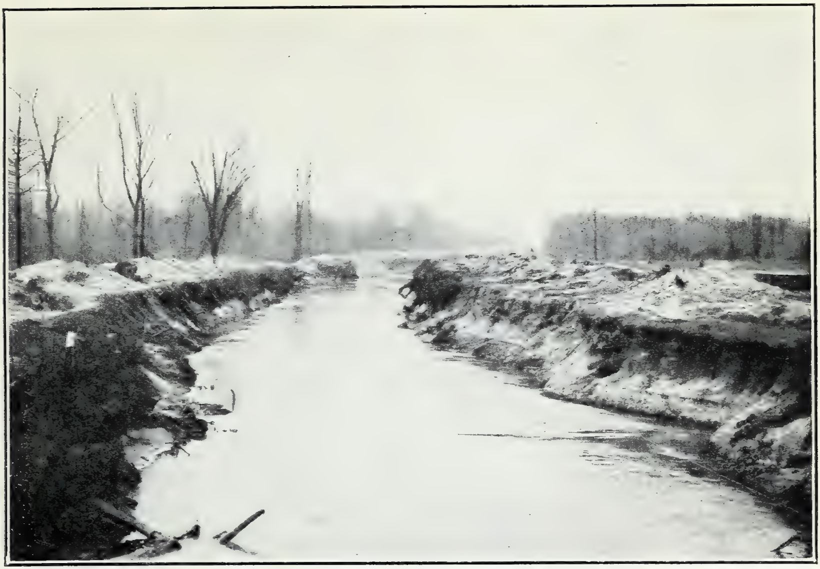
B. P. R.—D1376

FIG. 1.—SLOPE COURSE OF SUGAR CREEK DREDGED CHANNEL, NEAR HENDERSON, TENN., 1917. (SEE TABLE NO. 3.)



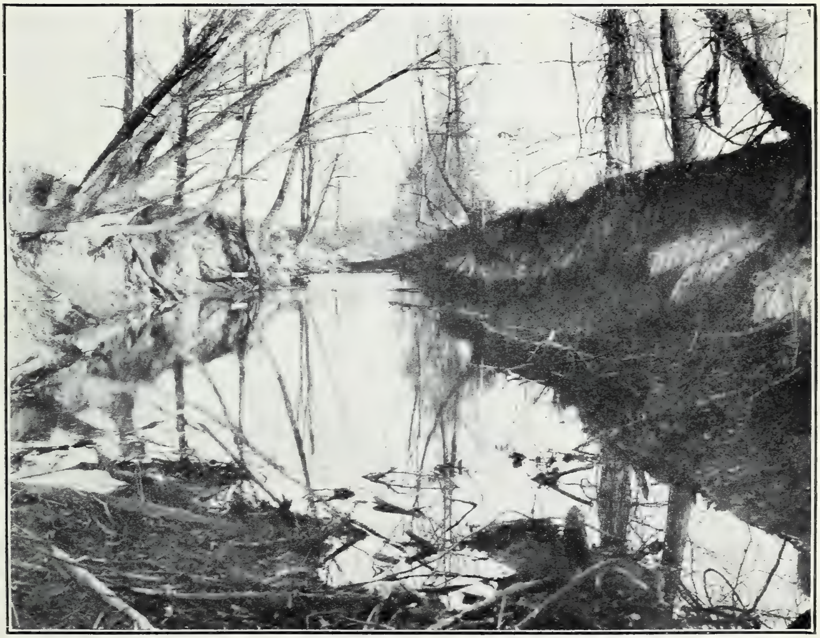
B. P. R.—D1332

FIG. 2.—SLOPE COURSE OF CYPRESS CREEK DREDGED CHANNEL, NEAR BETHEL SPRINGS, TENN., 1917. (SEE TABLE NO. 3.)



B. P. R.—D269

FIG. 1.—SLOPE COURSE OF SOUTH FORKED DEER RIVER DREDGED CHANNEL AT CAMPBELL'S LEVEE, NEAR JACKSON, TENN., 1916. (SEE TABLE NO. 3.)



B. P. R.—D710

FIG. 2.—SLOPE COURSE OF SOUTH FORKED DEER RIVER (OLD STRAIGHT RIVER CHANNEL) AT CAMPBELL'S LEVEE, NEAR JACKSON, TENN., 1916. (SEE TABLE NO. 3.)

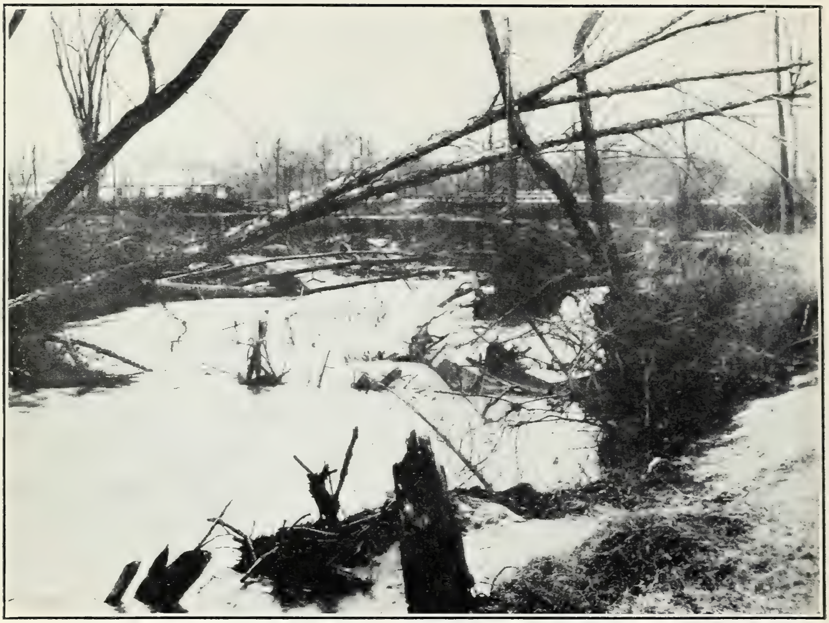

B. P. R.—D271

FIG. 1.—SLOPE COURSE OF SOUTH FORKED DEER RIVER (OLD CROOKED RIVER CHANNEL) AT CAMPBELL'S LEVEE, NEAR JACKSON, TENN., 1916. (SEE TABLE NO. 3.)

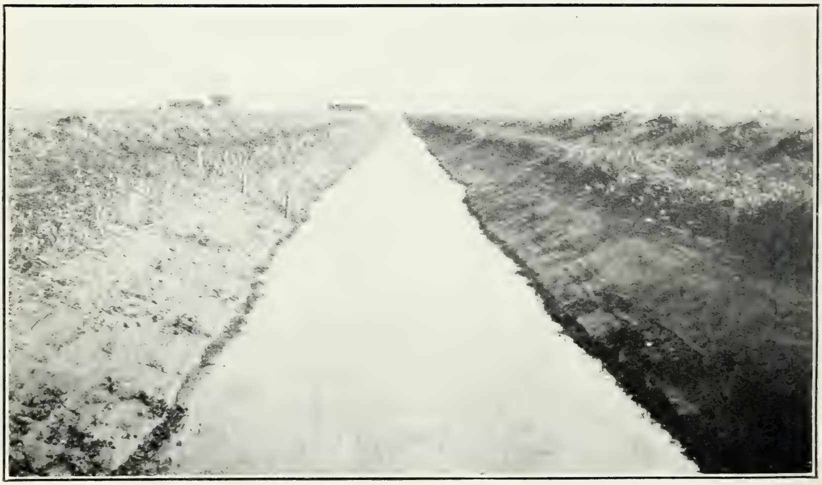
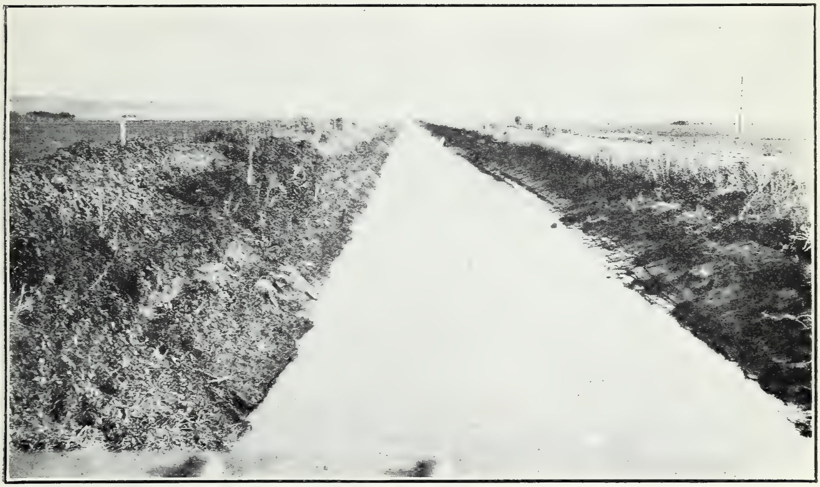
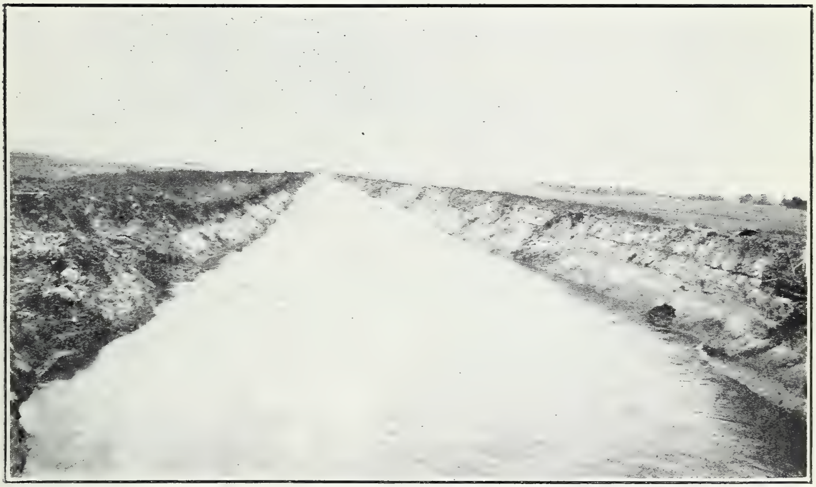

B. P. R.—D1202

FIG. 2.—SLOPE COURSE OF ALLEN CREEK DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA, 1917. (SEE TABLE NO. 4.)



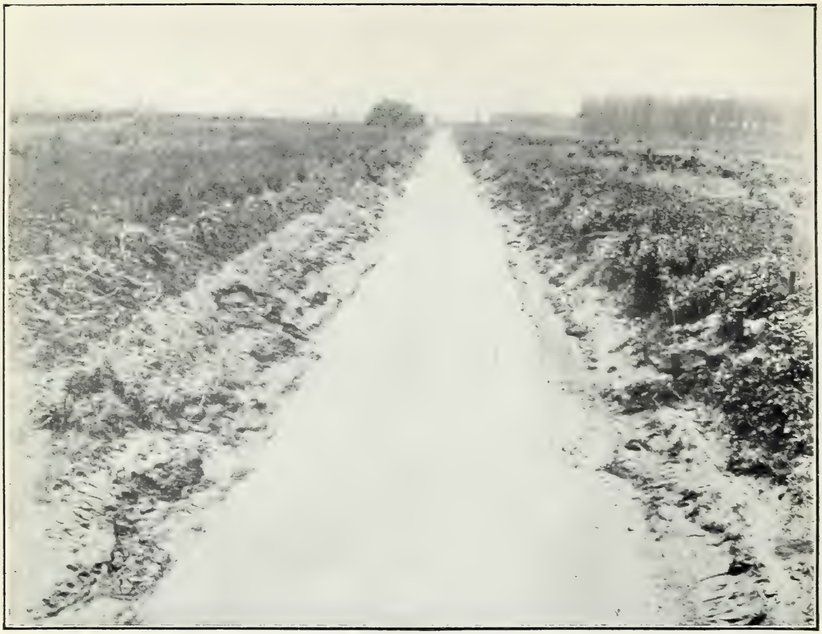
B. P. R.—D1203

FIG. 1.—SLOPE COURSE OF WILLOW CREEK DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA, 1917. (SEE TABLE NO. 4.)



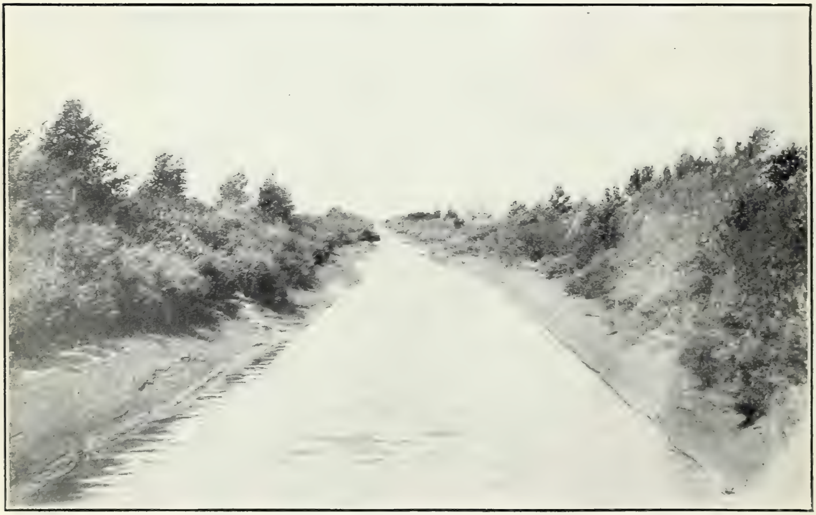
B. P. R.—D1200

FIG. 2.—SLOPE COURSE OF BOYER RIVER DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA, 1917. (SEE TABLE NO. 4.)



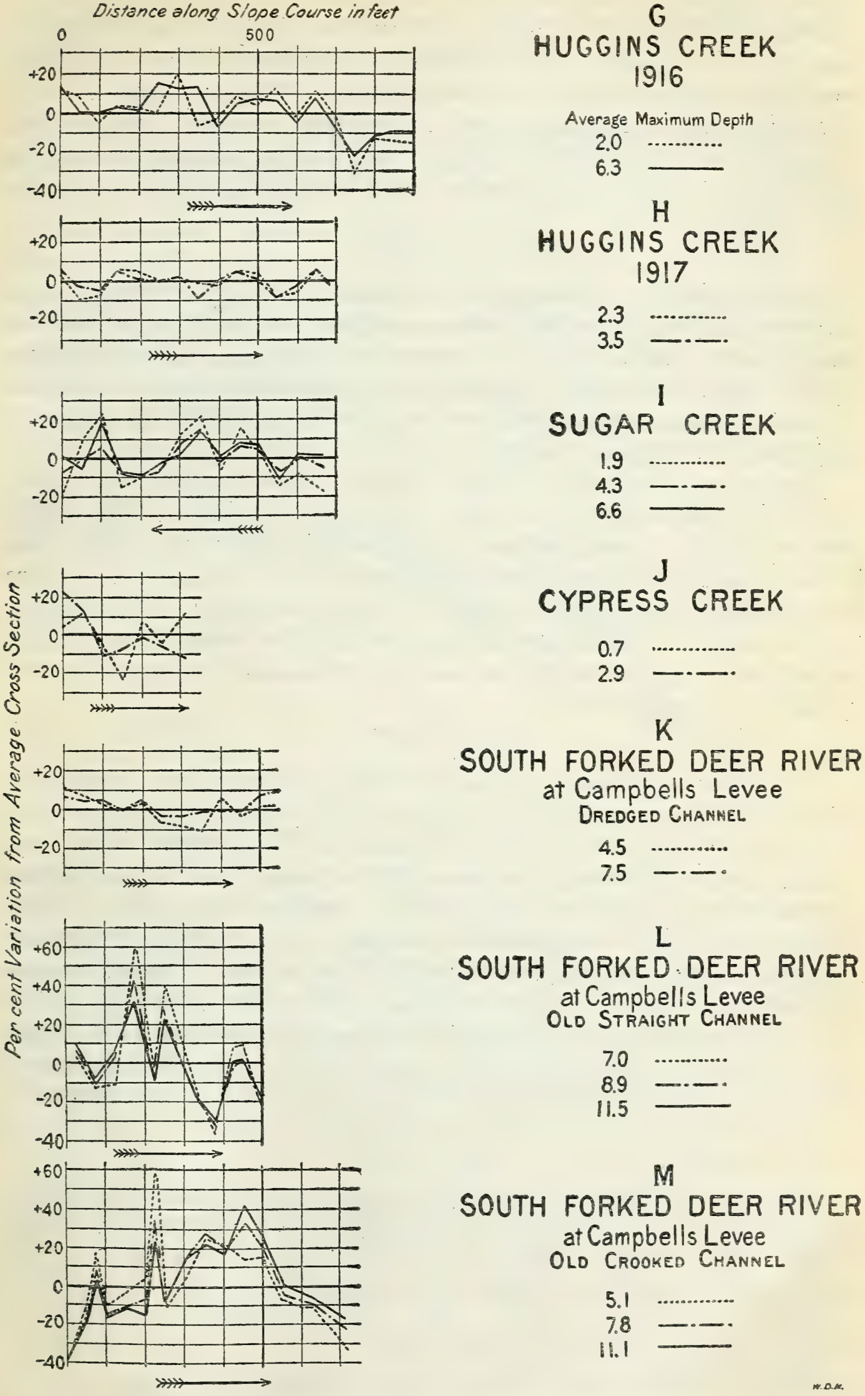
B. P. R.—D1284

FIG. 1.—SLOPE COURSE OF PIGEON CREEK DREDGED CHANNEL, NEAR CRESCENT, IOWA, 1917. (SEE TABLE NO. 4.)



B. P. R.—D2420

FIG. 2.—SLOPE COURSE OF MONONA-HARRISON DREDGED CHANNEL, NEAR ONAWA. IOWA, 1916. (SEE TABLE NO. 4.)



from average cross-sectional area for all cross sections along slope courses.

channel due to erosion during the interval of time between the above measurements was 23.5 per cent, from which it is seen that the erosion of the channel in this particular instance produced practically no change in the value of *n* for the channel. The low values of *n* for the higher stages as compared with the results obtained for the other channels may be attributed to the absence of abrupt changes in cross section and to the freedom from growth and obstructions in the channel.

### HUGGINS CREEK.

The Huggins Creek gauging station was located on the single-span highway bridge about 100 yards east of the Mobile & Ohio Railroad, near Finger, Tenn. The slope course was straight, extended downstream from the gauging station, and was 914 feet long for the first series of experiments and 686 feet long for the second (Plate IX, fig. 2; and figs. 5 *E*, 6 *G*, and 6 *H*).

The values obtained at Finger (Table 3, measurements 38 to 50) are fairly consistent for all stages and are rather high. This is due to the fact that irregularities and growth in the channel are quite evenly distributed from top to bottom of the channel and to large variations in cross section. This channel is rapidly deteriorating, due to caving of the banks and to growth in the channel, which fact is indicated by the higher values of *n* obtained during the second period of investigations,

### SUGAR CREEK.

The gauging station for Sugar Creek was located on a single-span highway bridge a short distance above the Mobile & Ohio Railroad, and about one-half mile from Henderson. The slope course was located below the bridge and was 669 feet long, the first half of the course being straight and the last half a smooth, easy curve. There was found to be no appreciable difference in the slope as between the curved and straight portions of the slope course. Abrupt changes in the size of the channel occurred along the slope course (figs. 5 *F*, and 6 *I*), and the lower portion of the channel was rough and irregular, not having been finished up properly at the time of construction. (See Table 3 for values of *n* and Plate X, fig. 1, for view of channel.)

### CYPRESS CREEK.

Gaugings of Cypress Creek were made from the single-span cattle bridge about 200 yards above the highway bridge at Bethel Springs, Tenn. This bridge was located on the slope course, close to the lower end. The slope course was straight and 308 feet in length.

Values of *n* for the high stages were not obtained for Cypress Creek. The values obtained (see Table 3, measurements 60 to 62) are high, as is the case on most of the channels at low stages, and are due to irregularities and vegetation in the channel. It is likely that a lower value of $n$ would have been obtained for a bankful stage. (See Plate X, fig. 2; and figs. 5 *G*, and 6 *J*.)

### SOUTH FORKED DEER RIVER AT CAMPBELL'S LEVEE ROAD.

Experiments were conducted on the river channel at the Campbell's levee road, near Jackson, to determine the values of $n$ for three different but consecutive courses, viz: Old channel (straight and crooked) and new, irregular, dredged channel. The relation of these courses as to location and alignment is shown in figure 6*X*. A good comparison for the courses can be made, since the values of $n$ for the different courses were computed from the same discharge measurements, made from a suspension footbridge at the upper end of the old straight course, so that any error in discharge would not materially affect the relative values of $n$. The results obtained, and a detailed description of the three different courses, are given in Table No. 3, measurements 63 to 76 (see Plate XI and Plate XII, fig. 1, for views of the three courses). The conditions found in the two sections of the old channel are typical of those prevailing in channels in this section of the country. The dredged channel is more irregular in shape of cross section than is the usual dredged channel in this part of the country. (For cross sections and variation in size of channel along slope courses see figs. 5 *H*, 5 *I*, 5 *J*, 6 *K*, 6 *L*, and 6 *M*.)

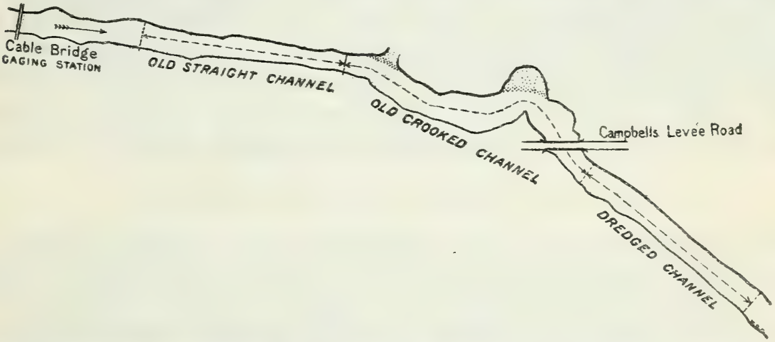


FIG. 6x.—Slope course at Campbells Levee, South Forked Deer River, near Jackson, Tenn.

In comparing the values of $n$ obtained for the fourth measurement in each channel (Table 3, measurements 66, 70, and 75) it is seen that the values are 0.0367, 0.0619, and 0.146 for the dredged, old straight, and old crooked channels, respectively; also that the slopes required for the same discharge is more than three times as much for the old straight channel as for the dredged channel, and about nine times as much for the old crooked channel. In order to show the relative capacities for these three courses of channel, for the values of $n$ given above, the following computations were made in which the slope, hydraulic radius, and cross-sectional area for measurement 66 were used.

[Cross-sectional area=315.6 square feet. Hydraulic radius=5.45 feet. Slope=0.0003.]

| Channel. | $n$ | $C$ | Mean velocity. | Discharge. | Relative discharges. |
|---|---|---|---|---|---|
| | | | *Ft. per sec.* | *Sec. feet.* | *Per cent.* |
| Dredged | 0.0367 | 56.2 | 2.27 | 715.1 | 100.0 |
| Old straight | .0619 | 34.8 | 1.40 | 443.5 | 62.1 |
| Old crooked | .1460 | 15.1 | 0.61 | 192.7 | 27.0 |

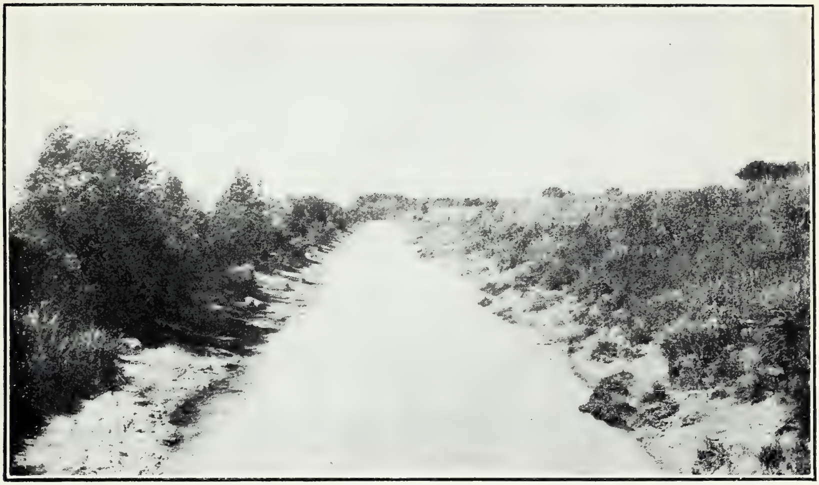
Results of the above computations show that for similar cross sections and slope the dredged, old straight, and old crooked channels would carry 715.1, 443.5, and 192.7 second-feet, respectively, the capacity of the old straight channel being only 62.1 per cent of that of the dredged, and of the old crooked channel only 27 per cent of the dredged. The difference in the capacities of the old straight channel and old crooked channel is not due entirely to the curves in the latter, since the accumulation of drift, trees, and logs was greater in the crooked channel. However, the difference in the condition of the two channels may be directly attributed to the presence of the curves, since there is a greater tendency for drift and other obstructions to accumulate in a crooked than in a straight course of channel.

### DISCUSSION OF WESTERN TENNESSEE EXPERIMENTS.

The experiments in western Tennessee cover a greater variety of conditions in channels than do any of the other six sets, the values of $n$ obtained ranging from 0.024 for the dredged channels near Roberts and Trenton to 0.162 for the old crooked river channel near Jackson. The results, however, do not justify the use of a coefficient as low as the first named above in the design of dredged channels, since it is not the rule that a dredged channel maintains its original efficiency. It is not believed that a value of $n$ less than 0.030 should be used for this section of the country, and it will be noted that this statement is in agreement with the conclusions deduced for the two sets of experiments made in Mississippi. Where it is desired to compute the capacity of an existing channel, the proper value of $n$ can be selected by a comparison of the conditions in the channel with the conditions described for the various channels for which $n$ has been determined in these experiments.

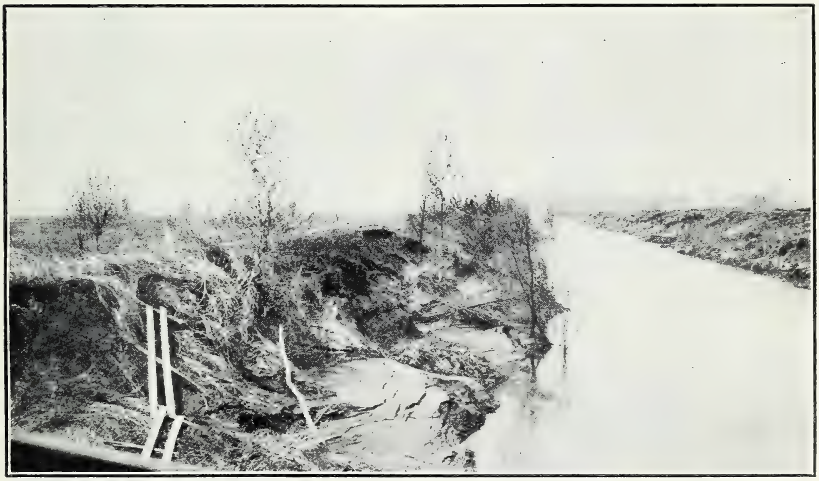
### EXPERIMENTS IN WESTERN IOWA.

Experiments in western Iowa were conducted on the following streams: Allen Creek, Willow Creek, Pigeon Creek, Boyer River, the Monona-Harrison Ditch, and Little Sioux River.



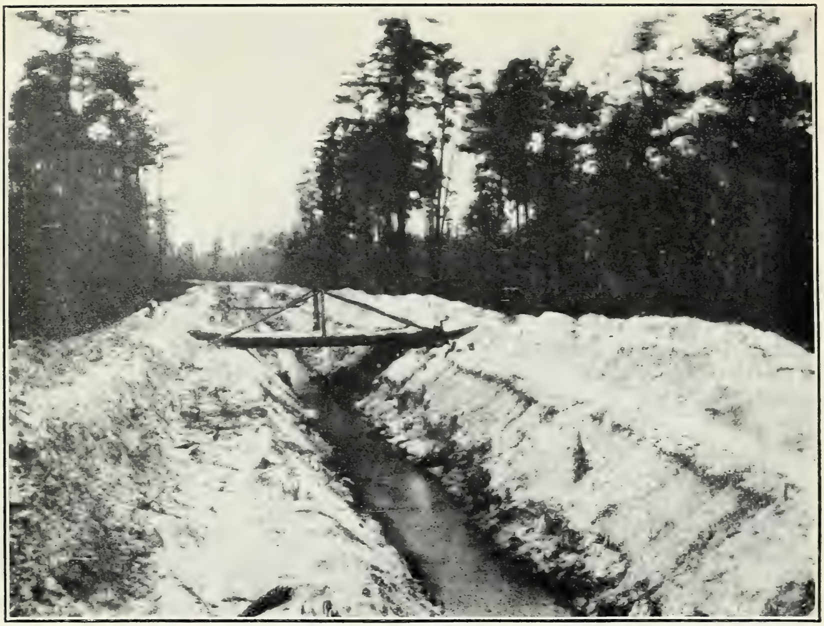
B. P. R.—D2425

FIG. 1.—SLOPE COURSE OF LITTLE SIOUX RIVER CUT-OFF DREDGED CHANNEL, NEAR TURIN, IOWA, 1916. (SEE TABLE NO. 4.)



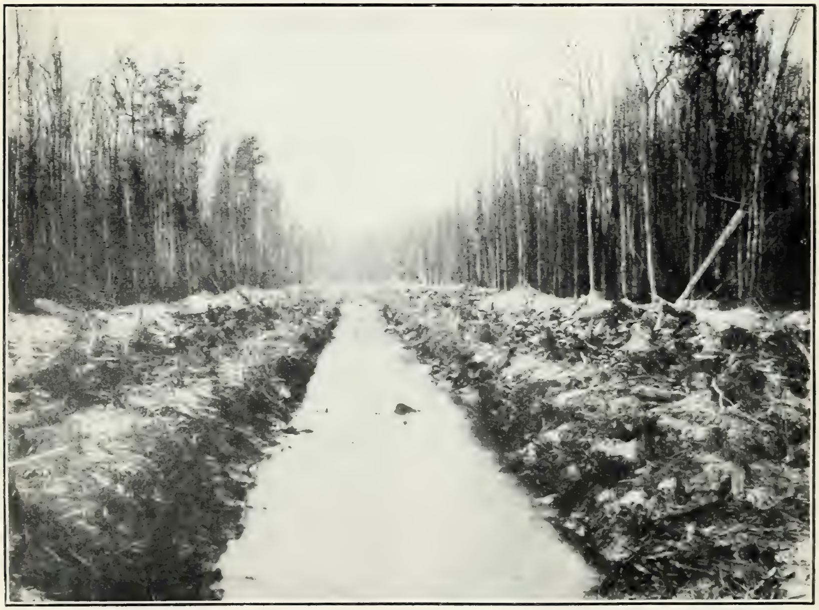
B. P. R.—D1087

FIG. 2.—SAME VIEW AS ABOVE, 1917.



B. P. R.—D1931

FIG. 1.—SLOPE COURSE OF TURKEY BRANCH DREDGED CHANNEL NEAR PEMBROKE, N. C., 1915. (SEE TABLE NO. 5.)



B. P. R.—D1868

FIG. 2.—SLOPE COURSE OF BACK SWAMP DREDGED DITCH, NEAR LUMBERTON, N. C., 1915. (SEE TABLE NO. 5.)

TABLE 4.—*Results of experiments made in western Iowa.*

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ C. | Coefficient of roughness n. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ALLEN CREEK DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA. | | | | | | | | | | | |
| | | *Feet.* | *Feet.* | *Sec. feet.* | *Sq. ft.* | *Ft. per sec.* | *Feet.* | | | | |
| 1 | June 4, 1917 | 7.1 | 42.3 | 930.8 | 196.2 | 4.74 | 4.30 | 0.0002897 | 134.5 | 0.0140 | *Course*, straight; 794 feet long. *Cross section*, practically no variation in shape; for variation in size, see fig. 8 A. *Side slopes*, smooth and regular. *Bottom*, even and regular. *Soil*, heavy, dark, silty loam. *Condition*, practically no vegetation in channel; bottom covered with ½ to 1 foot of mud; sides covered with silt of slimy and slippery nature which was no doubt principally responsible for low value of *n*. *Constructed*, summer of 1916. (See Pl. XII, fig. 2; and fig. 7 A.) |
| 2 | ......do........ | 7.15 | 42.4 | 837.1 | 197.4 | 4.24 | 4.32 | .0002392 | 132.7 | .0142 | |
| | ................ | [1] 8.00 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |
| WILLOW CREEK DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA. | | | | | | | | | | | |
| 3 | June 4, 1917 | 6.3 | 45.5 | 897.6 | 216.1 | 4.15 | 4.46 | 0.0002023 | 138.3 | 0.0137 | *Course*, straight; 1,004 feet long. *Cross section*, practically no variation in shape; for variation in size, see fig. 8 B. *Side slopes*, left side slope smooth and even; other side somewhat uneven and irregular. *Bottom*, even and regular. *Soil*, heavy, dark, silty loam. *Condition*, very little vegetation in channel; presence of silt and mud practically the same as described for Allen Creek. *Constructed*, summer of 1916. (See Pl. XIII, fig. 1; and fig. 7 B.) |
| 4 | June 6, 1917 | 6.4 | 46.0 | 813.6 | 220.3 | 3.69 | 4.49 | .0001694 | 133.7 | .0143 | |
| 5 | June 4, 1917 | 7.4 | 48.5 | 1,195.0 | 273.5 | 4.37 | 5.17 | .0001624 | 150.7 | .0128 | |
| | ................ | [1] 9.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |
| BOYER RIVER DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA. | | | | | | | | | | | |
| 6 | June 8, 1917 | 5.3 | 64.0 | 904.5 | 288.0 | 3.14 | 4.29 | 0.0003340 | 83.1 | 0.0230 | *Course*, straight; 868 feet long. *Cross section*, considerable but gradual variations in shape; for variation in size; see fig. 8 C. *Side slopes*, fairly regular. *Bottom*, somewhat uneven and irregular. *Soil*, upper part, dark silty loam; lower part, hard yellow clay. *Condition*, practically no vegetation in channel; bottom and sides coated with layer of slippery silt. *Constructed*, 1910. (See Pl. XIII, fig. 2; and fig. 7 C.) |
| 7 | June 7, 1917 | 7.0 | 69.0 | 1,438.6 | 410.9 | 3.50 | 5.58 | .0002525 | 93.3 | .0214 | |
| 8 | June 6, 1917 | 10.5 | 76.0 | 2,707.4 | 663.7 | 4.08 | 7.80 | .0001883 | 106.5 | .0197 | |
| 9 | June 4, 1917 | 11.7 | 79.0 | 3,213.4 | 755.5 | 4.25 | 8.59 | .0001278 | 128.3 | .0165 | |
| 10 | ......do........ | 12.2 | 80.0 | 3,756.0 | 799.0 | 4.70 | 8.99 | .0001255 | 139.9 | .0151 | |
| | ................ | [1] 15.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |
| PIGEON CREEK DREDGED CHANNEL, NEAR CRESCENT, IOWA. | | | | | | | | | | | |
| 11 | June 6, 1917 | 11.7 | 48.5 | 1,685.1 | 329.8 | 5.11 | 6.18 | 0.000642 | 81.1 | 0.0249 | *Course*, straight; 858 feet long. *Cross section*, slight variation in shape; for variation in size, see fig. 8 D. *Side slopes*, left side fairly regular; right side rough and irregular. *Bottom*, slightly irregular. *Soil*, heavy, dark silty loam. *Condition*, very little vegetation in channel; bottom covered with ½ to 1 foot of mud; sides coated with slippery silt. *Constructed*, 1907. (See Pl. XIV, fig. 1; and fig. 7 D.) |
| | ................ | [1] 12.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |
| 12 | June 6, 1917 | 12.4 | 53.8 | 2,047.1 | 363.7 | 5.63 | 6.12 | .000621 | 91.4 | .0220 | |

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[1] Average maximum depth at bankful stage.

TABLE 4.—*Results of experiments made in western Iowa*—Continued.

MONONA-HARRISON DREDGED CHANNEL, NEAR ONAWA, IOWA, 1916.

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ $C$. | Coefficient of roughness $n$. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Feet.* | *Feet.* | *Second-feet.* | *Sq. ft.* | *Ft. per sec.* | *Feet.* | | | | |
| 13 | June 2, 1916 | 4.4 | 37.2 | 221.0 | 131.3 | 1.68 | 2.60 | 0.000267 | 63.9 | 0.0272 | *Course*, straight; 948 feet long. *Cross section*, slight variations in shape, abrupt variations in size. *Side slopes*, quite irregular, particularly upper part. *Bottom*, fairly regular. *Soil*, dark silty loam. *Condition*, considerable growth in upper portion of channel, none in lower; silty material deposited on bed and sides of channel. *Constructed*, 1910. (See Pl. XIV, fig. 2; and fig. 7 E.) |
| 14 | May 22, 1916 | 6.9 | 47.2 | 614.0 | 270.8 | 2.27 | 4.19 | .000261 | 68.6 | .0278 | |
| ........ | | [1] 10.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |
| | **MONONA-HARRISON DREDGED CHANNEL, NEAR ONAWA, IOWA, 1917.** | | | | | | | | | | |
| 15 | June 8, 1917 | 8.5 | 59.8 | 499.0 | 308.0 | 1.62 | 4.82 | 0.000178 | 55.3 | 0.0362 | Practically no change in channel since measurements were made in 1916. |
| 16 | June 9, 1917 | 8.8 | 61.5 | 546.5 | 322.1 | 1.70 | 4.92 | .0001475 | 63.2 | .0320 | |
| ........ | | [1] 10.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |
| | **LITTLE SIOUX RIVER CUT-OFF DREDGED CHANNEL, NEAR TURIN, IOWA, 1916.** | | | | | | | | | | |
| 17 | June 2, 1916 | 11.3 | 90.6 | 2,907.0 | 839.7 | 3.47 | 8.62 | 0.000480 | 54.0 | 0.042 | *Course*, straight; 1,212 feet long. *Cross section*, slight variations in shape, abrupt variations in size. *Side slopes*, left side quite regular; right side irregular. *Bottom*, uneven and rather irregular. *Soil*, upper, dark silty loam; lower, heavy firm clay. *Condition*, considerable vegetation on both slopes of channel; very little silt in channel. *Constructed*, 1910. (See Pl. XV, fig. 1; and fig. 7 F.) |
| 18 | May 22, 1916 | 12.7 | 92.0 | 3,208.0 | 969.4 | 3.31 | 9.61 | .000398 | 53.5 | .044 | |
| 19 | May 24, 1916 | 14.2 | 94.7 | 3,380.0 | 1,107.0 | 3.05 | 10.62 | .000305 | 53.6 | .046 | |
| ........ | | [1] 20.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |
| | **LITTLE SIOUX RIVER CUT-OFF DREDGED CHANNEL, NEAR TURIN, IOWA, 1917.** | | | | | | | | | | |
| 20 | June 9, 1917 | 18.8 | 113.2 | 4,505.5 | 1,332.8 | 3.38 | 10.77 | 0.000934 | 33.8 | 0.076 | *Course*, straight; 1,654 feet long. *Cross section*, considerable variation in shape; very abrupt variations in size. *Side slopes*, left side, considerably rougher than during 1916; right side, extremely rough and irregular. *Bottom*, uneven and irregular. *Soil*, same as described next above. *Condition*, since 1916 measurements, right bank covered with trees and willows, which have slipped into channel; channel in very bad condition. *Constructed*, 1910. (See Pl. XV, fig. 2; and fig. 7 F.) |
| 21 | June 8, 1917 | [1] 19.1 | 113.6 | 4,887.0 | 1,374.0 | 3.56 | 11.0 | .000932 | 35.0 | .075 | |

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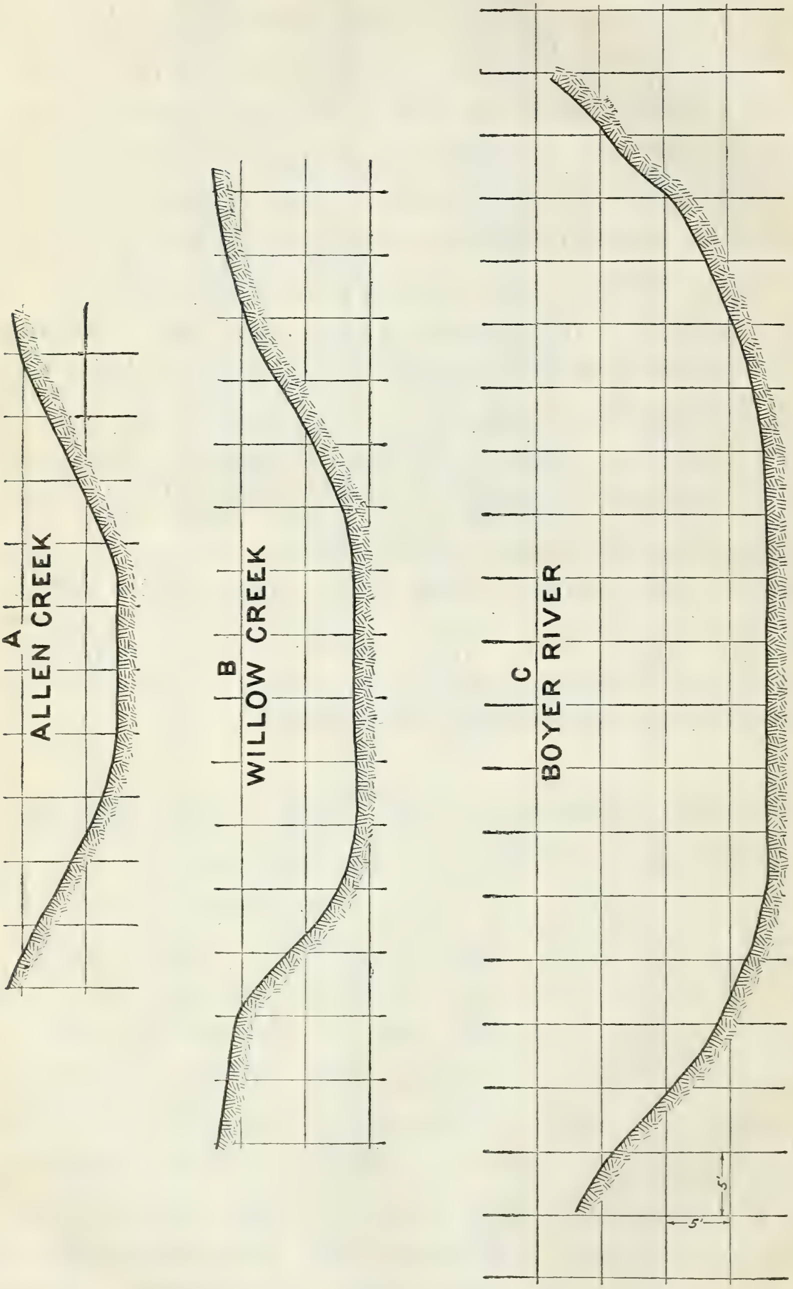
[1] Average maximum depth at bankful stage.

### ALLEN CREEK.

Gaugings of Allen Creek were made from the first highway bridge north of the Chicago & North Western Railroad about 1 mile west of Missouri Valley. The upstream end of the course for slope measurements, which was 794 feet in length, was about 130 feet downstream from the bridge. A view of the slope course is shown in Plate XII, figure 2. It is seen from this view and from figure 7 *A*, that the course is straight and that the side slopes of the channel are very smooth and regular and stand at a slope of about 1½ to 1. No appreciable amount of vegetation can be seen in the channel. This stream was enlarged to its present size during the summer of 1916, and the measurements for values of *n* were made about one year later. The soil in the channel is a heavy dark loam. The bottom of the channel is generally covered with soft mud to a depth of one-half to 1 foot, and the side slopes, after high stages in the channel, are left covered with a coat of slippery, slimy mud or silt. This coat can be seen by an inspection of Plate XII, figure 2. Two values of *n* were determined for practically bankful stages. These values are 0.0140 and 0.0142 (Table 4, measurements 1 and 2), which are exceedingly low for dredged drainage ditches and may be ascribed in part to the excellent condition of the channel and the uniformity of cross section (fig. 8 *A*), but mostly to the actual lining of the entire perimeter of the channel with a coating of slimy, slippery mud. This coating of mud no doubt greatly decreased the friction between the moving water and perimeter of the channel.

### WILLOW CREEK.

Discharge measurements of the Willow Creek dredged channel were made at the Chicago & North Western Railroad bridge near Missouri Valley. The slope posts for the upper end of the slope course were set about 155 feet below the bridge, the length of the course being 1,004 feet. It can be seen from figures 7 *B*, and 8 *B*, and Plate XIII, figure 1, that the slope course is straight and very uniform in cross section. The left side slope is much more regular and smooth than the right side slope and resembles the slopes of the Allen Creek ditch in this respect. Some vegetation can be seen in the channel, but it was not present when the gaugings and slope measurements were made. This channel is comparatively new, having been enlarged to its present size during the summer of 1916, and these measurements were made and views taken about one year later. The soil in the channel is a heavy dark loam, similar to that found in the Allen Creek channel. The bottom of the channel was covered with from 1 to 1½ feet of mud during these experiments, and the coating of the perimeter of the channel with slimy mud during high stages was practically the same as in Allen Creek. In general, the channel


A
ALLEN CREEK
B
WILLOW CREEK
C
BOYER RIVER
5'
5'

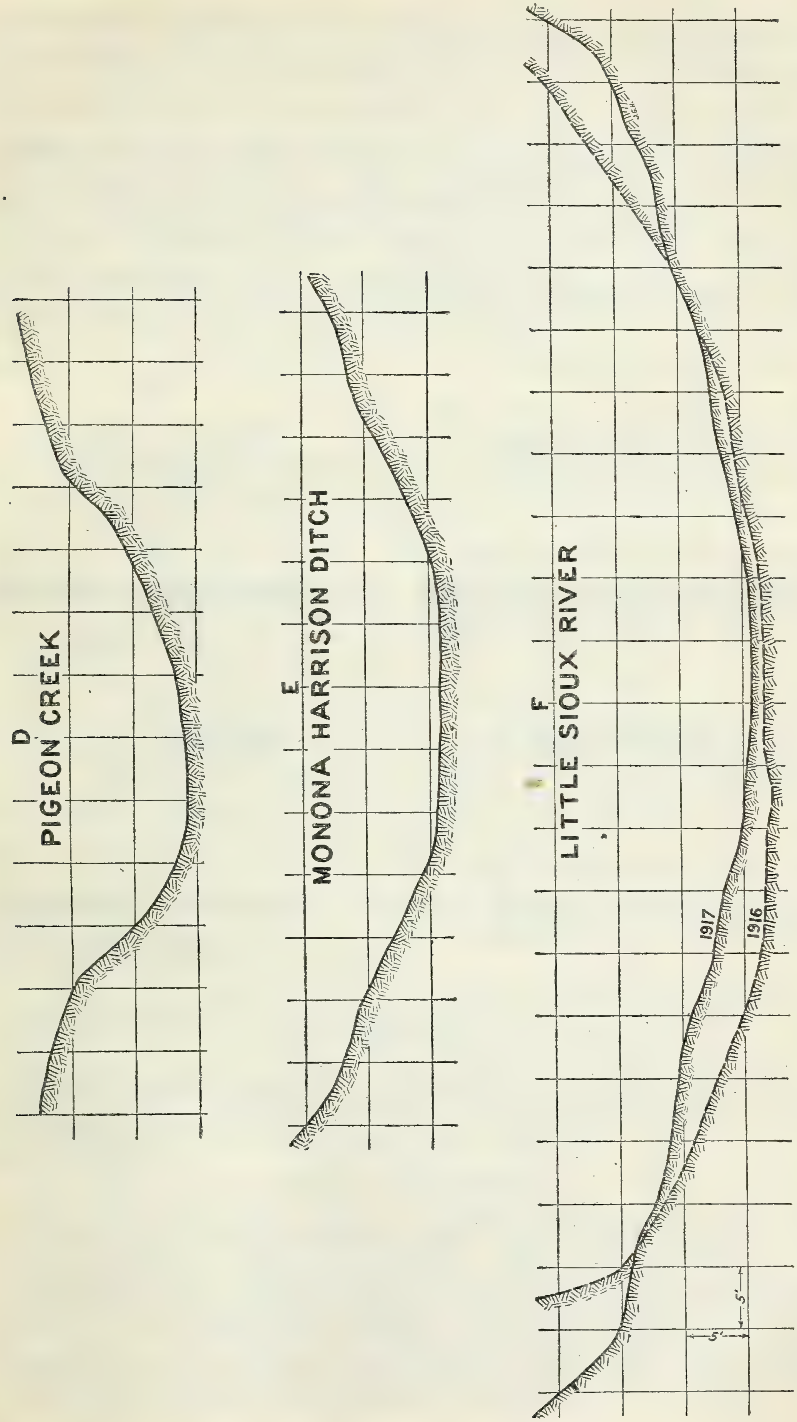


FIG. 7.—Average cross sections of channels for experiments in western Iowa.

is very similar to that of Allen Creek, and the values of $n$ obtained, as given in Table 4, are practically the same as those obtained for Allen Creek.

### BOYER RIVER.

Gaugings of the Boyer River were made at the Lincoln Highway bridge about 1 mile from Missouri Valley. The downstream end of the slope course was 197 feet above the bridge. The length of the slope course was 868 feet. A view of the slope course looking upstream is shown in Plate XIII, figure 2. The downstream slope posts are barely visible on the left-hand side of the view, just above the break in the bank. It can be seen that above this break in the bank the course of the channel is straight and fairly uniform in cross section (fig. 8 $C$). The sides of the upper part of the channel stand at a slope of about 1 to 1 (see fig. 7 $C$). The soil in the upper part of the sides of the channel consists of a dark loam and in the lower part it is a hard yellow clay. The channel is practically free from any form of vegetation, which condition is largely due to its rapid enlargement caused by erosion. Since the channel was constructed, in 1910, it has enlarged to almost double its original size.

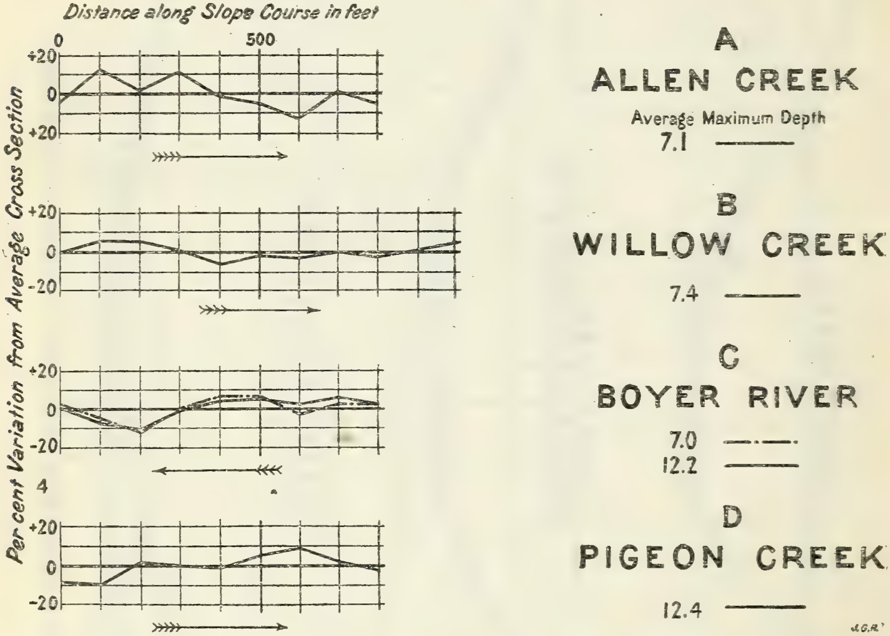


FIG. 8.—Graphs for experiments in western Iowa, showing per cent variation from average cross sectional area for all cross sections along slope course.

During flood stages the condition of the channel was very similar to that described for the Allen and Willow Creek channels. After the water subsided the sides of the channel were left coated with a thin layer of mud. The values of *n* obtained (Table 4) are higher than those obtained for Allen and Willow Creeks, which is attributed to the fact that the sides of the channel are considerably more irregular, as may be seen by comparing the views of the channels. Also, it is believed that the reduction of friction, due to the coating of mud on the sides of the channels, was much more effective on the rather flat side slopes of Willow and Allen Creeks than on the steeper side slopes of the Boyer River channel. It will be noted that, for the Boyer River channel, the value of *n* increases as the stage decreases. This is due, no doubt, to the fact that the lower part of the channel is more irregular than the upper part.

### PIGEON CREEK.

Gaugings of Pigeon Creek were made at the highway bridge about one-half mile above the Chicago & North Western Railroad, near the town of Crescent. A view of the course of slope measurements is shown in Plate XIV, figure 1. This view was taken looking downstream from the gauging station. The upstream slope posts, which were about 65 feet below the bridge, can be seen on the right-hand side of the view.

The upper portion of the sides of the channel stand at a slope of about 1 to 1 (see figs. 7 *D*, and 8 *D*). There was very little vegetation in the channel when the gaugings and slope measurements were made. The soil in the channel is a heavy dark loam, and the bottom of the channel is generally covered with ½ to 1 foot of mud. The channel was dug in 1907, and has increased somewhat in depth since that time but not much in width. The right bank of the channel is rather smooth and regular, while the left bank is rough and irregular. During flood stages the channel was coated with mud, as described for the channels near Missouri Valley.

In Table 4, measurements 11 and 12, are shown two values of *n* obtained for high stages in the channel. These values are much larger than those obtained for Willow and Allen Creeks, which is perhaps due to the rougher condition and greater fall of the channel, both of which conditions probably rendered less effective the mud coating in reducing friction.

### MONONA-HARRISON DITCH.

A view of the slope course on the Monona-Harrison ditch, near Onawa, is shown in Plate XIV, figure 2. This view was taken looking upstream from the gauging station, which was located at the highway bridge on the Turin-Onawa road. The length of the slope course was 948 feet. Experiments were made during the years 1916 and 1917, and not much difference was found in the size and condition of the channel for the two sets of measurements. In Table 4 are given the values of $n$ obtained for the years 1916 and 1917, respectively. From this table it is seen that the values of $n$ obtained for the low stages during 1916 are lower than those obtained for the higher stages during 1917. This is due to the fact that the upper portion of the channel is irregular and covered with growth, as may be seen from the view of of the channel. During the gaugings and slope measurements the water was not as fully laden with silt as in the case of the ditches in the vicinity of the Missouri Valley, nor were the sides of the channel so well coated with mud. The bed and the flatter portions of the sides of the channel were covered with silt, varying in depth from ½ to 1½ feet. (See fig. 7 *E* for average cross section of channel.)

### LITTLE SIOUX RIVER CUT-OFF.

Gaugings of the Little Sioux River were made from the highway bridge on the Onawa-Turin road, about one-half mile from Turin. Values of $n$ for the channel were obtained during 1916 and 1917. Views of the slope course taken during June, 1916, and June, 1917, are shown in Plates XV, figures 1 and 2. The length of the slope course for the measurements made in 1916 was 1, 212 feet, and for those made in 1917 was 1,654 feet. The slope course was located on the straight stretch of channel above the gauging station at the highway bridge. The soil in the upper part of the channel is a dark silty loam, while in the lower part it is a heavy firm clay. There was practically no silt in the bed of the channel during the time that the experiments were made. The channel during 1916 was fairly uniform in section, and the left bank, which is shown on the right-hand side of the view (Pl. XV, fig. 1), was quite regular. The right bank was somewhat irregular, due to caving. (See fig. 7 *F*, for average cross sections of the channel.) There was some vegetation on both side slopes of the channel, as may be seen from the view. The values of $n$ obtained for this channel, shown in Table 4, are about what would be expected for a channel in its condition.

Plate XV, figure 2, shows the condition of the same channel in June, 1917. The right bank, which in 1916 was covered with trees, has caved into the channel, and the left bank is considerably rougher than it was in June, 1916. The two values of $n$ obtained, 0.075 and 0.076, are considerably higher than those obtained in 1916. This may readily be ascribed to the caving of the right bank, which carried into the channel large trees and other obstructions. The water during the experiments was not laden with silt, as in the case of the ditches near Missouri Valley, and the channel was not coated with mud after the subsidence of the water.

### DISCUSSION OF WESTERN IOWA EXPERIMENTS.

The low values of *n* obtained for the Allen and Willow Creek Ditches (0.0128 to 0.0143) are, so far as the writer knows, without precedent for dredged channels. From a close examination of the views of these channels one would expect low values of *n* for channels with such regular and smooth side slopes and uniform cross sections. However, the fact that the values of *n* are so low can not be attributed alone to these conditions, since a low value of *n* was obtained for a bankful stage of the Boyer River channel, which does not fulfill these ideal conditions of regularity and uniformity. The low values are therefore due mostly, no doubt, to the coating of slick, silty mud with which the perimeters of the channel were covered, the tendency being to smooth up irregularities. It is not conclusively apparent why the values of *n* for Pigeon Creek are so much higher than for Willow Creek since the conditions of the ditches are somewhat similar. It is possible that the slight difference in the condition of the channel and the greater fall rendered the mud coating less effective in reducing frictional resistance.

In view of the results obtained for Pigeon Creek, the Monona-Harrison Ditch, and the lower part of the Boyer River channel, it is possible that the effectiveness of this coating of mud in reducing friction is affected by vegetation, roughness of channel, angle of side slopes, irregularity of cross section, and slope of channel. It is not recommended that such low values of *n* as obtained for Allen and Willow Creeks be employed in the design of proposed dredged drainage channels unless there is no question but that all the conditions of the Allen and Willow Creek channels will be duplicated. It should also be remembered that these ditches are comparatively new, and unless the proposed ditches are to be carefully maintained to keep the channels free of growth and obstructions, and unless there is good reason to believe that they will retain their original smooth slopes and uniform cross section, a low value of *n* should not be used, even though the silty conditions as described above could be expected to prevail.

### EXPERIMENTS IN NORTH CAROLINA.

Values of *n* were determined for five courses of channels in Back Swamp and Jacob Swamp, North Carolina, namely: Turkey Branch, Back Swamp, Jacob Swamp at Lovett Road, Little Jacob Swamp, and Jacob Swamp at the Nashville & Chattanooga Railroad. These experiments were made by A. D. Morehouse, formerly a drainage engineer of this bureau.

TABLE 5.—*Results of experiments made in North Carolina.*

| No. | Date of observation. | Average maximum depth. | Average surface width. | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ $C$. | Coefficient of roughness $n$. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | TURKEY BRANCH HAND-DUG CHANNEL NEAR PEMBROKE, N. C. | | | | | | | | | | |
| | | *Feet.* | *Feet.* | *Sec. feet.* | *Sq. ft.* | *Ft. per sec.* | *Feet.* | | | | |
| 1 | Jan. 29, 1915 | 0.7 | 4.8 | 2.5 | 3.2 | 0.78 | 0.56 | 0.000915 | 34.5 | 0.0325 | *Course*, straight; 200 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 10 A. *Side slopes*, quite regular. *Bottom*, fairly regular; changes occur due to silting and erosion. *Soil*, sandy clay. *Condition*, free from vegetation of all kinds. *Constructed*, summer 1913. (See Pl. XVI, fig. 1; and fig. 9 A.) |
| 2 | Jan. 14, 1915 | .9 | 5.5 | 4.3 | 3.9 | 1.11 | .62 | .000790 | 50.2 | .0243 | |
| 3 | Jan. 20, 1915 | .95 | 5.7 | 4.7 | 4.0 | 1.17 | .64 | .001010 | 46.0 | .0266 | |
| | .............. | [1] 5.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | | |
| | BACK SWAMP DREDGED CHANNEL NEAR LUMBERTON, N. C. | | | | | | | | | | |
| 4 | Apr. 22, 1915 | 2.5 | 22.5 | 28.5 | 25.3 | 1.13 | 1.22 | 0.000792 | 36.3 | 0.0382 | *Course*, straight; 250 feet long. *Cross section*, abrupt variations in shape; for variation in size, see fig. 10 B. *Side slopes*, fairly regular. *Bottom*, fairly regular, some holes. *Soil*, sandy clay. *Condition*, mat of overhanging ragged roots on both side slopes; no weeds or grass in channel; some roots in bottom. *Constructed*, winter 1913. (See Pl. XVI, fig. 2; and fig. 9 B.) |
| 5 | Feb. 10, 1915 | 2.9 | 23.1 | 40.0 | 32.0 | 1.25 | 1.45 | .000880 | 35.0 | .0417 | |
| 6 | May 17, 1915 | 3.1 | 23.3 | 58.6 | 35.6 | 1.65 | 1.57 | .000880 | 44.4 | .0340 | |
| 7 | Feb. 3, 1915 | 4.4 | 24.6 | 129.6 | 66.0 | 1.96 | 2.51 | .000624 | 49.5 | .0345 | |
| 8 | Jan. 20, 1915 | 5.1 | 25.2 | 171.9 | 83.1 | 2.07 | 2.98 | .000600 | 49.0 | .0363 | |
| 9 | May 13, 1915 | 5.7 | 25.8 | 232.5 | 98.8 | 2.35 | 3.34 | .000730 | 47.7 | .0383 | |
| 10 | Jan. 25, 1915 | 5.75 | 26.0 | 235.1 | 99.3 | 2.37 | 3.34 | .000640 | 51.2 | .0359 | |
| | .............. | [1] 6.5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |
| | JACOB SWAMP DREDGED CHANNEL AT LOVETT ROAD, NEAR LUMBERTON, N. C. | | | | | | | | | | |
| 11 | Feb. 22, 1915 | 1.5 | 22.3 | 6.5 | 13.0 | 0.50 | 0.67 | 0.000493 | 27.6 | 0.0405 | *Course*, straight; 300 feet long. *Cross section*, rather abrupt variations in shape; for variation in size, see fig. 10 C. *Side slopes*, fairly regular. *Bottom*, fairly even and regular. *Soil*, sandy clay loam. *Condition*, not much vegetation in channel, except for last measurement, at which time two-thirds of the bottom and side slopes were covered with water grass. *Constructed*, April, 1913. (See Pl. XVII, fig. 1; and fig. 9 C.) |
| 12 | Jan. 19, 1915 | 2.2 | 21.4 | 30.1 | 28.3 | 1.06 | 1.19 | .000317 | 54.6 | .0262 | |
| 13 | Jan. 25, 1915 | 2.3 | 24.7 | 32.0 | 29.8 | 1.07 | 1.23 | .000443 | 45.7 | .0312 | |
| 14 | Feb. 2, 1915 | 2.5 | 25.2 | 13.7 | 35.0 | 1.25 | 1.41 | .000373 | 54.6 | .0274 | |
| 15 | May 13, 1915 | 3.2 | 26.0 | 51.0 | 49.4 | 1.03 | 1.81 | .000550 | 32.6 | .0475 | |
| | .............. | [1] 6.0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | |

### LITTLE JACOB SWAMP DREDGED CHANNEL NEAR LUMBERTON, N. C.

DURING WINTER MONTHS.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | Feb. 22, 1915 | 0.9 | 13.0 | 6.5 | 10.3 | 0.63 | 0.69 | 0.000448 | 35.8 | 0.0332 | *Course*, straight; 500 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 10 D. *Side slopes*, fairly regular. *Bottom*, quite even and regular. *Soil*, clay; sandy bottom due to silting. *Condition*, some moss along course; very little foreign material in channel. *Constructed*, July, 1913. (See Pl. XVII, fig. 2; and fig. 9 D.) |
| 17 | Jan. 13, 1915 | 1.0 | 13.6 | 13.7 | 12.4 | 1.10 | .79 | .000738 | 45.4 | .0282 | |
| 18 | Jan. 19, 1915 | 1.5 | 17.2 | 24.1 | 19.6 | 1.23 | 1.08 | .000630 | 47.1 | .0293 | |
| 19 | Jan. 25, 1915 | 1.6 | 17.5 | 26.7 | 20.5 | 1.30 | 1.11 | .000566 | 52.0 | .0270 | |
| | .............. | [1] 7.0 | ....... | ......... | ....... | ....... | ....... | ......... | ......... | ....... | |

DURING SUMMER MONTHS.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | June 28, 1915 | 0.65 | 10.0 | 2.2 | 6.3 | 0.35 | 0.50 | 0.000308 | 28.2 | 0.0362 | *Course*, same as next above. *Condition*, light growth of grass and weeds along edge of low water flow. |
| 21 | June 15, 1915 | .7 | 10.5 | 2.8 | 6.8 | .41 | .53 | .000314 | 31.7 | .0335 | |
| 22 | June 11, 1915 | .8 | 11.0 | 4.5 | 8.6 | .52 | .62 | .000322 | 36.8 | .0310 | |
| 23 | May 19, 1915 | .9 | 12.0 | 5.4 | 10.1 | .53 | .70 | .000360 | 33.3 | .0348 | |
| 24 | May 15, 1915 | 1.4 | 17.0 | 15.4 | 17.4 | .89 | 1.01 | .000318 | 49.7 | .0272 | |
| 25 | May 13, 1915 | 2.2 | 20.0 | 29.5 | 32.9 | .90 | 1.55 | .000176 | 54.5 | .0275 | |
| | .............. | [1] 7.0 | ....... | ......... | ....... | ....... | ....... | ......... | ......... | ....... | |

### JACOB SWAMP DREDGED CHANNEL AT N. & C. R. R. NEAR LUMBERTON, N. C.

DURING WINTER MONTHS.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | Mar. 4, 1915 | 1.1 | 19.5 | 9.6 | 14.9 | 0.64 | 0.67 | 0.000593 | 32.1 | 0.0357 | *Course*, straight; 300 feet long. *Cross section*, rather abrupt variations in shape; for variation in size, see fig. 10 E. *Side slopes*, irregular. *Bottom*, fairly even and regular. *Soil*, clay loam. *Condition*, some roots and dead vegetation in channel. *Constructed*, April, 1913. (See Pl. XVIII, fig. 1; and fig. 9 E.) |
| 27 | Feb. 22, 1915 | 1.3 | 20.8 | 17.7 | 19.2 | .92 | .84 | .000470 | 46.2 | .0276 | |
| 28 | Jan. 19, 1915 | 2.3 | 25.1 | 64.3 | 47.7 | 1.35 | 1.72 | .000503 | 45.9 | .0357 | |
| 29 | Jan. 25, 1915 | 2.4 | 25.9 | 71.1 | 49.7 | 1.43 | 1.78 | .000350 | 57.2 | .0276 | |
| 30 | Feb. 2, 1915 | 2.9 | 26.3 | 112.8 | 65.2 | 1.73 | 2.21 | .000531 | 50.5 | .0330 | |
| | .............. | [1] 6.5 | ....... | ......... | ....... | ....... | ....... | ......... | ......... | ....... | |

DURING SUMMER MONTHS.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | June 11, 1915 | 1.2 | 19.0 | 8.9 | 22.4 | 0.40 | 0.93 | 0.000560 | 17.6 | 0.0680 | *Course*, same as next above. *Condition*, growth of water grass and weeds in channel. |
| 32 | May 19, 1915 | 1.4 | 20.2 | 11.8 | 25.6 | .46 | 1.05 | .000590 | 18.4 | .0675 | |
| 33 | May 17, 1915 | 1.6 | 21.0 | 20.6 | 31.2 | .66 | 1.25 | .000483 | 26.8 | .0508 | |
| 34 | May 15, 1915 | 2.1 | 23.2 | 37.8 | 43.8 | .86 | 1.64 | .000437 | 32.0 | .0470 | |
| 35 | May 13, 1915 | 3.4 | 27.7 | 96.2 | 79.4 | 1.21 | 2.56 | .000423 | 36.7 | .0470 | |
| | .............. | [1] 6.5 | ....... | ......... | ....... | ....... | ....... | ......... | ......... | ....... | |

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[1] Average maximum depth at bankful stage.

### TURKEY BRANCH.

A straight course 200 feet long was selected for slope measurements on the Turkey Branch channel just above the Atlantic Coast Line Railroad southwest of Pembroke. This channel is small and was hand-dug (Plate XVI fig. 1; and fig. 9 *A*). At the time of the experiments the channel was very uniform in cross section for a bankful stage; it had regular side slopes and was free from growth of any kind. The values of $n$ obtained were only for very low stages. As may be seen from Table 5, the average maximum depth for the channel at bankful stage was 5.0 feet, and only 0.95 foot for the highest stage for which $n$ was determined. The cross sectional area of the lower part of the channel varied considerably in size (fig. 10 *A*).

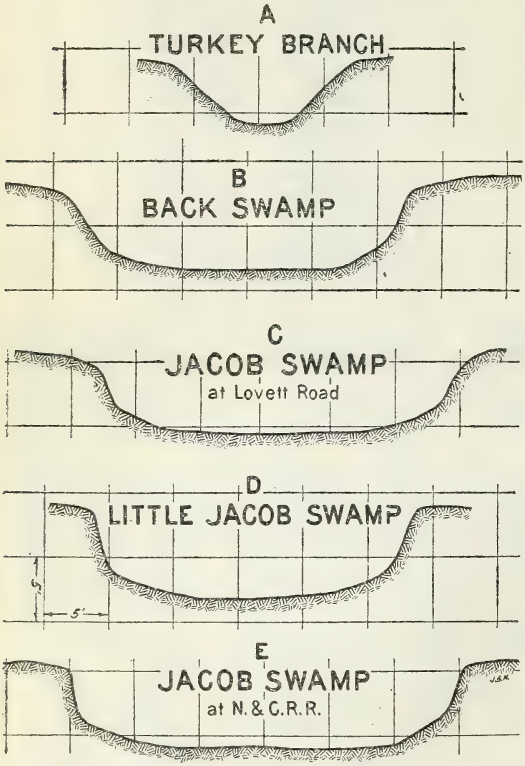
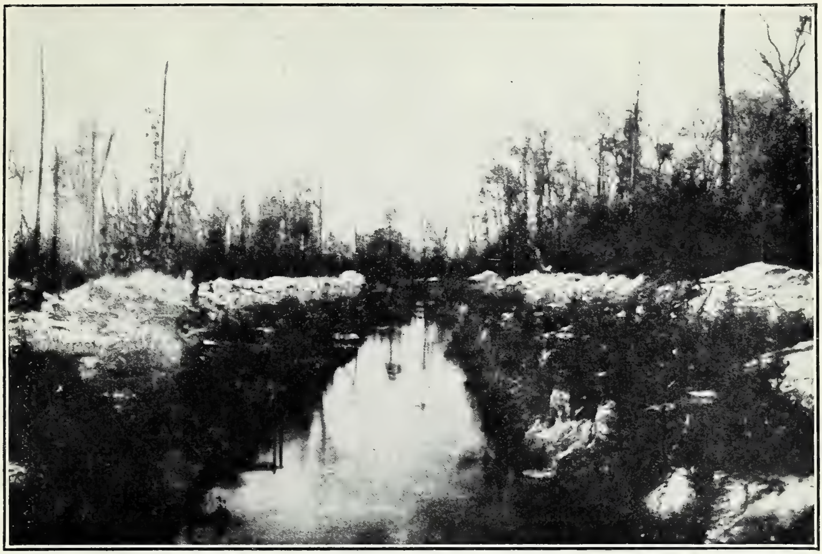


FIG. 9.—Average cross sections of channels for experiments in North Carolina.

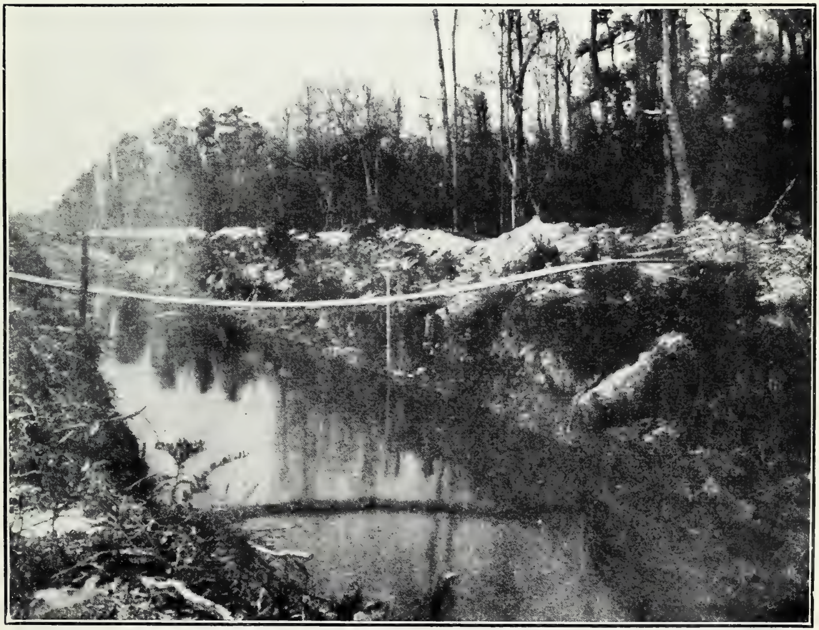
### BACK SWAMP.

A straight course of channel 250 feet in length was used for slope measurements on the Back Swamp channel. It was located just west of the Sunday Ford Road and about 8 miles west of Lumberton. At the time of these measurements the channel was quite uniform in cross section, and the side slopes were quite regular (fig. 10, *B*). The side slopes have been eroded considerably so as to be nearly vertical, leaving a mat of overhanging ragged roots on either bank. Owing to a comparatively swift current, there were no weeds, grass, or other vegetation on the bottom or side slopes, but there were a number of large tree roots in the channel. Plate XVI, figure 2; and figure 9 *B*, show the condition and average cross section of channel, and Table 5 shows the values obtained for $n$. Of the five channels for which experiments were made, this is the only one where a value of $n$ was determined for a near bankful stage.



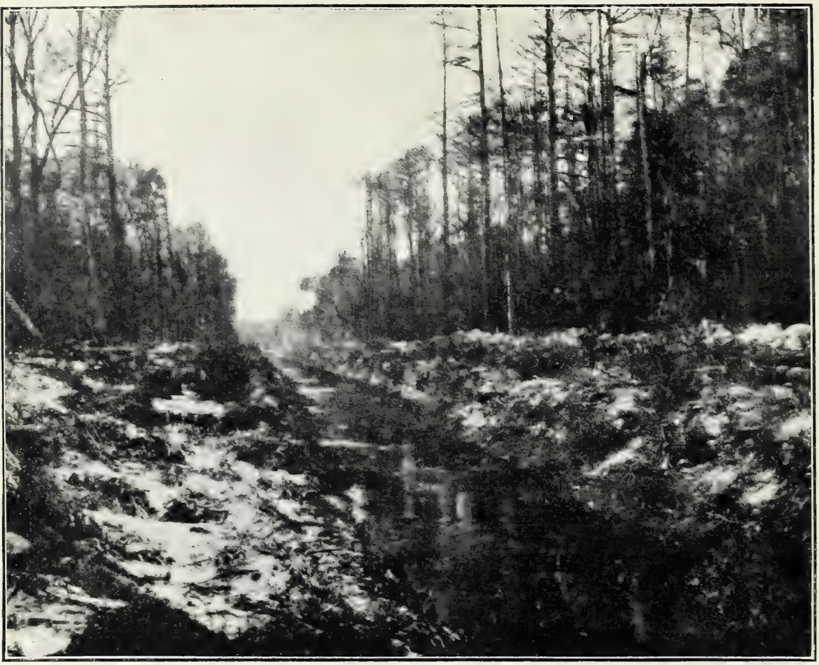
B. P. R.—D3063

FIG. 1.—SLOPE COURSE OF JACOB SWAMP DREDGED CHANNEL AT LOVETT ROAD, NEAR LUMBERTON, N. C. (SEE TABLE NO. 5.)



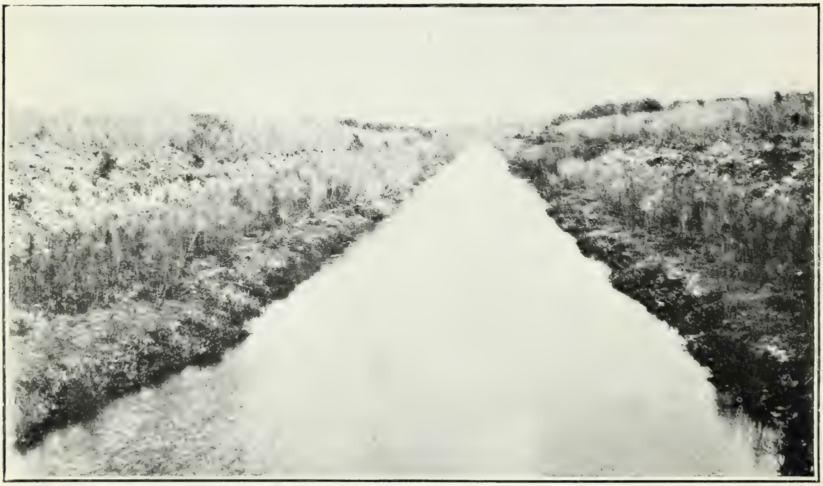
B. P. R.—D3065

FIG. 2.—SLOPE COURSE OF LITTLE JACOB SWAMP DREDGED CHANNEL, NEAR LUMBERTON, N. C., 1915. (SEE TABLE NO. 5.)



B. P. R.—D3064

FIG. 1.—SLOPE COURSE OF JACOB SWAMP DREDGED CHANNEL AT N. & C. R. R., NEAR LUMBERTON, N. C., 1915. (SEE TABLE NO. 5.)



B. P. R.—D941

FIG. 2.—COURSE OF MAIN DREDGED CHANNEL, NEAR FELLSMERE, FLA., ADJOINING SLOPE COURSE. THIS VIEW REPRESENTS FAIRLY WELL THE CONDITION OF THE CHANNEL ALONG THE SLOPE COURSE. 1917. (SEE TABLE NO. 6.)

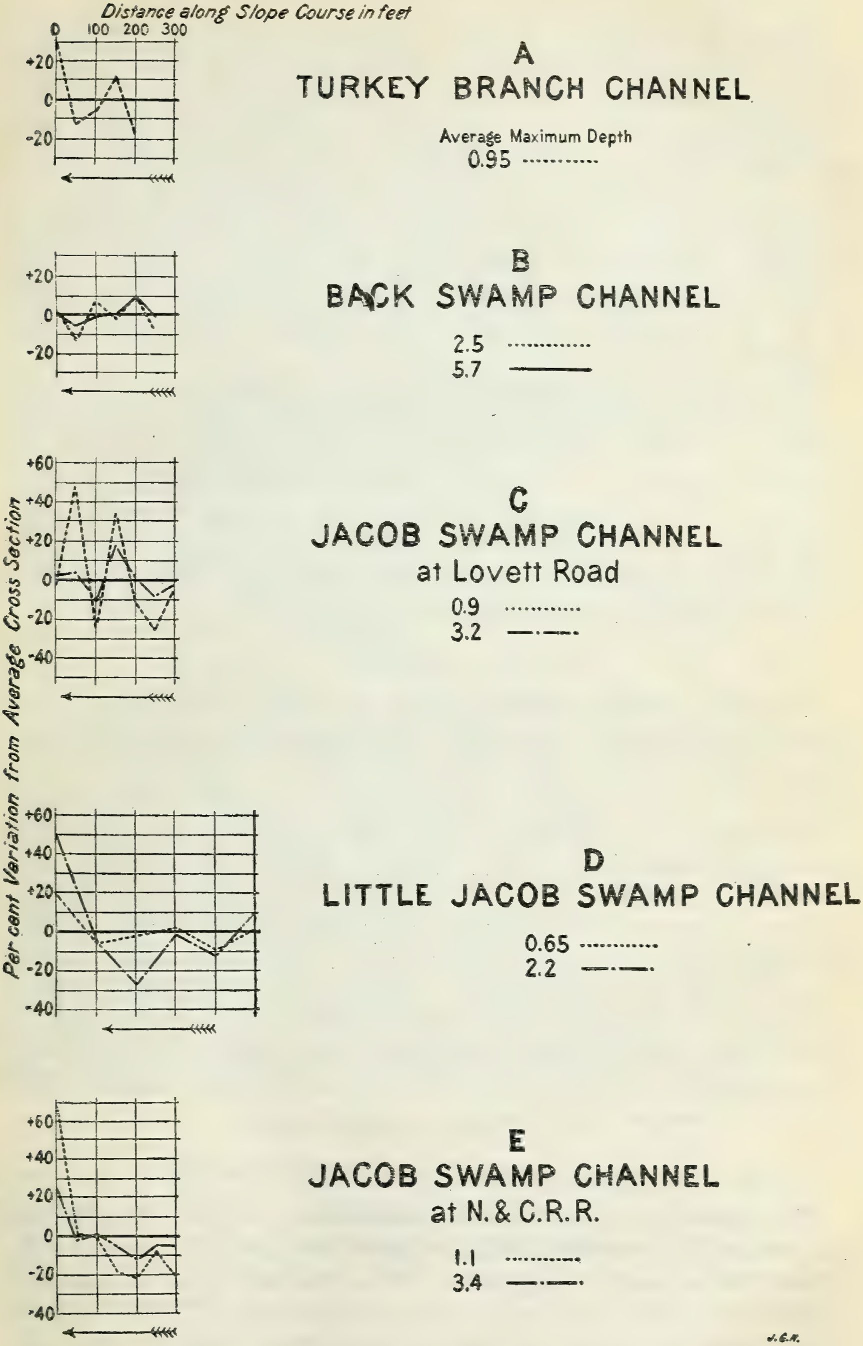


FIG. 10.—Graphs for experiments in North Carolina, showing per cent variation from average cross-sectional area for all cross sections along slope courses.

### JACOB SWAMP AT LOVETT ROAD.

A slope course 300 feet in length, just west of the Lovett Road and about 2 miles south of Lumberton, was selected for slope measurements on this channel. The cross section was fairly uniform for the higher stages and the side slopes and bottom fairly regular. For the lower stages there was considerable variation in cross section (fig. 10 *C*). There was practically no vegetation in the channel when the measurements were made during January and February, but for the single measurement made during May about two-thirds of the bottom and side slopes were covered with water grass. (See Plate XVII, fig. 1, for view and fig. 9 *C*, for average cross section of the channel.)

During low water the thread of the stream wanders from side to side, which, with the large and abrupt variations in cross sections, is no doubt responsible for the high value of $n$ obtained for the lowest stage (measurement 11, Table 5). The high value obtained for measurement 15 is due, of course, to the growth of grass in the channel. This value was obtained for about half-bankful stage. Values for higher stages were not obtained, so that none of the values of $n$ given in Table 5 apply to the channel when flowing full.

### LITTLE JACOB SWAMP.

A straight course 500 feet in length, just west of the Lovett Road about 2½ miles south of Lumberton, was used for slope measurements. This course was fairly uniform in cross section for a distance of about 450 feet from the upper end of the slope course, with quite regular side slopes and bottom (fig. 10 *D*). There was very little growth in the channel during the winter months. Plate XVII, figure 2, is a view of the channel and figure 9 *D*, shows the average cross section. During the summer months grass and weeds appear in the channel, especially along the edge of the water, and there were several patches of moss along the slope course. There was not sufficient growth in the channel to produce a very marked effect upon the value of $n$, as may be seen from the small difference in the results of the measurements as given in Table 5 for the winter and summer months. The values of $n$ were obtained for only very low stages.

### JACOB SWAMP AT NASHVILLE & CHATTANOOGA RAILROAD.

The slope course used on this channel was 300 feet in length and was located just west of the Nashville & Chattanooga Railroad trestle, about 2 miles south of Lumberton. The cross section of this course of channel was fairly uniform for a distance of about 275 feet from the upper end of the course, but the side slopes were rather irregular (fig.

10 *E*) There were some roots and dead vegetation in the channel during the winter months. Silting had occurred along the course, and there was a mud island 3 feet wide by 10 feet long lying lengthwise of the channel a short distance above the lower end of the slope course. During the summer months the island was covered with water grass. There was also a growth of grass along the edge of low-water stages and two patches of grass in the channel along the course.

The highest stages for which values of $n$ were determined were about half-bankful. Referring to Table 5, it can be seen that the values of $n$ obtained during the summer months are higher than those obtained during the winter months, owing to the growth of grass in the channel; also that the values for the summer months increase as the stage decreases, due no doubt to the fact that for the lower stages the grass filled a much greater proportion of the cross-sectional area of the channel. Plate XVIII, figure 1, is a view of the channel, and figure 9 *E* shows the average cross section.

### DISCUSSION OF NORTH CAROLINA EXPERIMENTS.

Attention is especially called to the fact that in these experiments values of $n$ were not obtained for bankful stages, and this should be kept in mind when comparing the views and descriptions of the channels with the values of $n$ obtained. A value of $n$ for a near-bankful stage was obtained on the Back Swamp channel, but in the other channels the highest stages for which values of $n$ were determined were about half, and in some instances considerably less than half, of a bankful stage.

The chief value of these experiments lies in the fact that values of $n$ were determined before and after the growth of grass in three of the channels, from which a general idea can be obtained as to the retarding effect of grass upon the flow in water courses.

With the exception of Back Swamp the discharges of the channels were quite small, and for this reason it is not believed that the results are as accurate as were obtained for the other experiments herein discussed, since the effect of errors in making small discharge measurements is usually greater than in the measurement of large discharges.

### EXPERIMENTS IN FLORIDA.

These experiments were made on the main channels of the Fellsmere, Vero, and Fort Pierce Drainage Districts, and on two courses of Lateral No. 2 of the Fort Pierce Drainage District. They were conducted by F. E. Staebner, drainage engineer of this bureau, during 1916 and 1917.

TABLE 6.—*Results of experiments made in Florida.*

MAIN DREDGED CHANNEL NEAR FELLSMERE, FLA., 1916.

| No. | Date of observation. | Average maximum depth. | Average surface width | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ C. | Coefficient of roughness n. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Feet.* | *Feet.* | *Sec.-ft.* | *Sq. ft.* | *Ft. per sec.* | *Feet.* | | | | |
| 1 | Oct. 12, 1916 | 1.40 | 45.5 | 48.8 | 48.2 | 1.01 | 1.05 | 0.000328 | 54.5 | 0.0253 | *Course*, straight; 2,000 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 12 A. *Side slopes*, lower, fairly regular; upper, rather irregular. *Bottom*, regular and even. *Soil*, coarse sand on bottom, clay on sides. *Condition*, some vegetation, principally dog fennel, for higher stages; practically no vegetation for lower stages. *Constructed*, November, 1911. (See Pl. XVIII, fig. 2). |
| 2 | Dec. 5, 1916 | 1.7 | 46.4 | 64.7 | 63.1 | 1.02 | 1.32 | .000260 | 55.1 | .0264 | |
| 3 | Sept. 22, 1916 | 5.6 | 75.6 | 506.2 | 298.0 | 1.70 | 3.83 | .000222 | 58.3 | .0323 | |
| 4 | .....do........ | 5.7 | 76.5 | 534.0 | 302.2 | 1.77 | 3.83 | .000198 | 64.2 | .0292 | |
| 5 | .....do........ | 5.75 | 76.5 | 558.6 | 314.8 | 1.77 | 3.97 | .000205 | 62.3 | .0304 | |
| | .............. | [1] 15.9 | ....... | ....... | ....... | ....... | ....... | ....... | ....... | ....... | |

MAIN DREDGED CHANNEL NEAR FELLSMERE, FLA., 1917.

| No. | Date of observation. | Average maximum depth. | Average surface width | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ C. | Coefficient of roughness n. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | Feb. 10, 1917 | 1.6 | 45.6 | 44.2 | 48.1 | 0.92 | 1.05 | 0.000259 | 55.8 | 0.0251 | Condition of channel practically the same as during the 1916 measurements. For variation in size of channel see fig. 12 B. See fig. 11 A for cross section. |
| 7 | July 12, 1917 | 2.3 | 49.3 | 94.7 | 83.1 | 1.14 | 1.66 | .000235 | 57.8 | .0266 | |
| 8 | Oct. 18, 1917 | 3.2 | 53.5 | 186.4 | 127.7 | 1.46 | 2.33 | .000236 | 62.1 | .0269 | |
| 9 | Sept. 29, 1917 | 5.0 | 68.8 | 403.1 | 241.4 | 1.67 | 3.15 | .000200 | 66.5 | .0269 | |
| 10 | .....do........ | 7.6 | 88.5 | 746.8 | 441.9 | 1.69 | 4.86 | .000185 | 56.3 | .0355 | |
| | .............. | [1] 15.9 | ....... | ....... | ....... | ....... | ....... | ....... | ....... | ....... | |

MAIN DREDGED CHANNEL NEAR VERO, FLA., 1916.

| No. | Date of observation. | Average maximum depth. | Average surface width | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ C. | Coefficient of roughness n. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | Aug. 14, 1916 | 1.2 | 47.7 | 41.1 | 44.6 | 0.92 | 0.92 | 0.000625 | 38.3 | 0.0337 | *Course*, straight; 1,000 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 12 C. *Side slopes*, fairly uniform and regular for lowest three stages; quite rough and irregular for highest two. *Bottom*, fairly even and regular. *Soil*, sand on bottom, clay on sides. *Condition*, some vegetation in lower part of channel; flat sand bars. *Constructed*, December, 1912. (See Pl. XIX, fig. 1; and fig. 11 B.) |
| 12 | Nov. 21, 1916 | 2.2 | 52.8 | 131.2 | 91.4 | 1.44 | 1.70 | .000478 | 50.4 | .0319 | |
| 13 | Oct. 5, 1916 | 2.8 | 55.9 | 201.4 | 128.6 | 1.57 | 2.25 | .000305 | 60.0 | .0278 | |
| 14 | Oct. 28, 1916 | 5.3 | 67.2 | 569.5 | 285.7 | 1.99 | 4.11 | .000479 | 44.9 | .0432 | |
| 15 | Oct. 29, 1916 | 6.9 | 73.1 | 955.2 | 397.3 | 2.40 | 5.26 | .000538 | 45.1 | .0460 | |
| | .............. | [1] 10.0 | ....... | ....... | ....... | ....... | ....... | ....... | ....... | ....... | |

MAIN DREDGED CHANNEL NEAR VERO, FLA., 1917.

| No. | Date of observation. | Average maximum depth. | Average surface width | Discharge. | Average cross section. | Mean velocity. | Mean hydraulic radius. | Slope of water surface. | Coefficient in formula $V=C\sqrt{RS}$ C. | Coefficient of roughness n. | Description of channel. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | Sept. 12, 1917 | 3.2 | 57.9 | 290.2 | 136.9 | 2.12 | 2.33 | 0.000406 | 69.0 | 0.0244 | Condition of channel, about the same as for the 1916 measurements. For variation in size of channel see fig. 12 D. |
| 17 | Oct. 19, 1917 | 4.7 | 67.6 | 533.2 | 234.9 | 2.27 | 3.41 | .000407 | 61.1 | .0299 | |
| 18 | Sept. 27, 1917 | 5.1 | 68.9 | 577.2 | 260.0 | 2.22 | 3.68 | .000416 | 56.8 | .0327 | |
| 19 | Sept. 25, 1917 | 5.7 | 71.3 | 712.5 | 307.1 | 2.32 | 4.18 | .000571 | 47.6 | .0404 | |
| | .............. | [1] 10.0 | ....... | ....... | ....... | ....... | ....... | ....... | ....... | ....... | |

MAIN DREDGED CHANNEL NEAR FORT PIERCE, FLA., 1916.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | Dec. 8, 1916 | 1.7 | 23.0 | 6.9 | 29.9 | 0.23 | 1.26 | 0.000125 | 18.3 | 0.0700 | *Course*, straight; 1,032 feet long. *Cross section*, not much variation in shape; for variation in size, see fig. 12 E. *Side slopes*, rather irregular. *Bottom*, rather rough. *Soil*, hard clay. *Condition*, some water weeds on bottom; growth of grass and lilies near water edge at low stage. (See Pl. XIX, fig. 2; and fig. 11 C.) |
| 21 | Nov. 7, 1916 | 3.5 | 28.3 | 62.8 | 74.2 | .85 | 2.62 | .000178 | 39.3 | .0435 | |
| 22 | Nov. 18, 1916 | 3.7 | 30.6 | 77.5 | 79.5 | .98 | 2.62 | .000161 | 47.6 | .0360 | |
| 23 | Nov. 4, 1916 | 5.1 | 32.2 | 139.3 | 125.8 | 1.11 | 3.56 | .000199 | 41.7 | .0450 | |
| 24 | Oct. 28, 1916 | 5.4 | 32.9 | 149.6 | 135.0 | 1.11 | 3.77 | .000203 | 40.1 | .0475 | |
| | | [1] 9.0 | | | | | | | | | |

MAIN DREDGED CHANNEL NEAR FORT PIERCE, FLA., 1917.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | Sept. 13, 1917 | 2.9 | 20.3 | 13.4 | 37.3 | 0.36 | 1.73 | 0.000070 | 32.7 | 0.0450 | *Course*, straight; 900 feet long. *Cross section*, not much variation in shape; for variation in size, see fig. 12 F. *Side slopes*, fairly regular. *Bottom*, irregular. *Soil*, hard clay. *Condition*, very little vegetation; channel was cleaned out and deepened since the 1916 measurements were made. (See fig. 11 C.) |
| 26 | Oct. 22, 1917 | 5.0 | 25.6 | 106.4 | 87.2 | 1.22 | 3.06 | .000163 | 54.5 | .0327 | |
| 27 | Oct. 20, 1917 | 5.8 | 26.8 | 155.8 | 109.7 | 1.42 | 3.58 | .000180 | 56.0 | .0331 | |
| 28 | Sept. 25, 1917 | 6.7 | 28.5 | 220.2 | 134.3 | 1.64 | 4.02 | .000220 | 55.1 | .0346 | |
| 29 | Oct. 17, 1917 | 6.9 | 28.1 | 234.1 | 138.5 | 1.69 | 4.09 | .000212 | 57.3 | .0334 | |
| | | [1] 11.5 | | | | | | | | | |

LATERAL DREDGED CHANNEL NO. 2, COURSE A, NEAR FORT PIERCE, FLA.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | Oct. 20, 1917 | 3.9 | 19.5 | 12.5 | 52.3 | 0.24 | 2.38 | 0.000027 | 29.9 | 0.0540 | *Course*, straight; 503 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 12 G. *Side slopes*, rather irregular. *Bottom*, slightly irregular. *Soil*, hard clay. *Condition*, some vegetation in channel. (See Pl. XX, fig. 1; and fig. 11 D.) |
| 31 | Oct. 17, 1917 | 5.0 | 22.0 | 37.6 | 75.1 | .50 | 2.87 | .000064 | 36.9 | .0470 | |
| | | [1] 8.5 | | | | | | | | | |

LATERAL DREDGED CHANNEL NO. 2, COURSE B, NEAR FORT PIERCE, FLA.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 | Oct. 20, 1917 | 2.2 | 30.1 | 10.5 | 38.8 | 0.27 | 1.27 | 0.000721 | 8.9 | 0.140 | *Course*, straight; 500 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 12 H. *Side slopes*, rather irregular. *Bottom*, fairly regular; occasional low pockets that hold water during periods of no flow. *Soil*, sandy and easily eroded. *Condition*, bad; channel practically covered with vegetation. (See Pl. XX, fig. 2; and fig. 11 E.) |
| 33 | Oct. 17, 1917 | 3.3 | 39.4 | 31.4 | 76.7 | .41 | 1.96 | .000423 | 14.2 | .108 | |
| | | [1] 4.0 | | | | | | | | | |

[1] Average maximum depth at bankful stage.

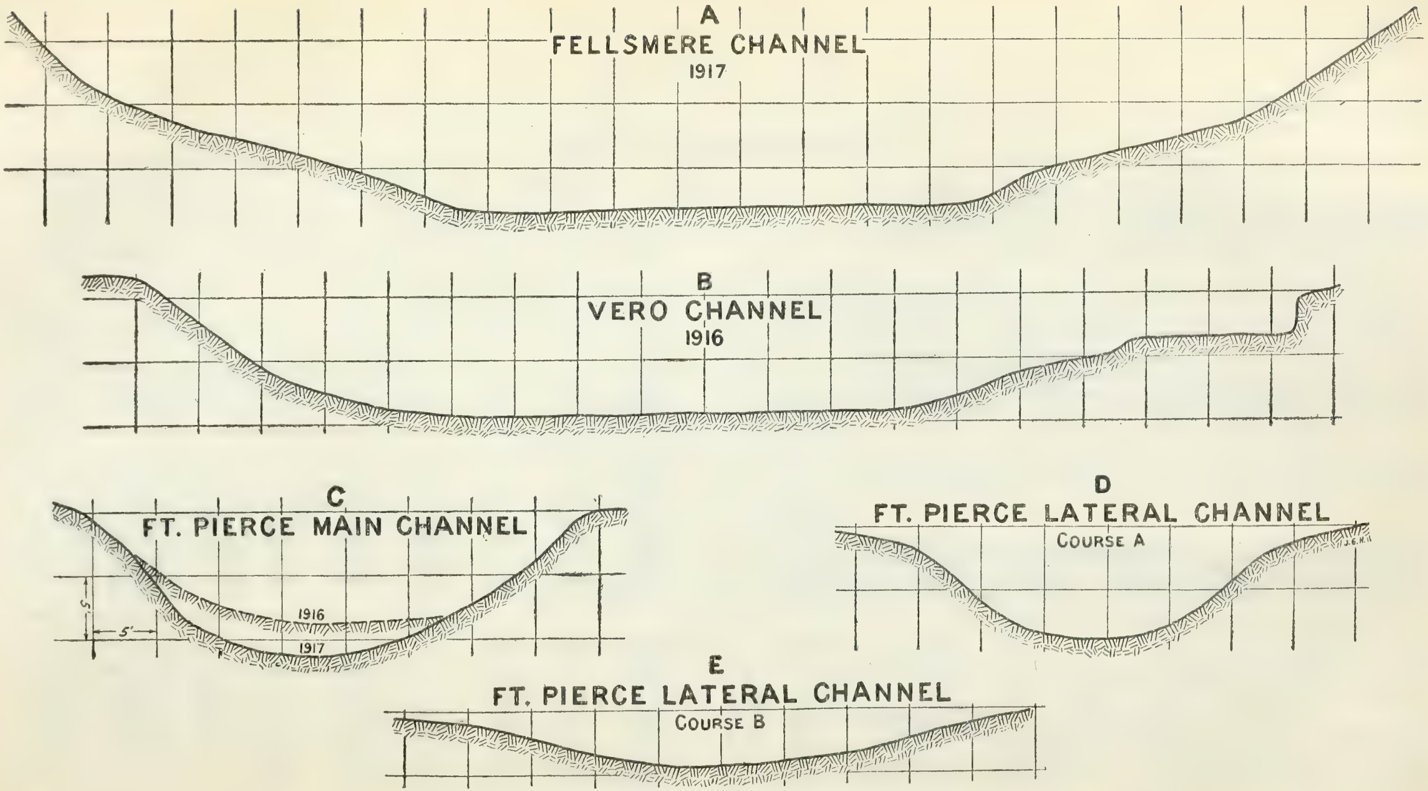


FIG. 11.—Average cross sections of channels for experiments in Florida.

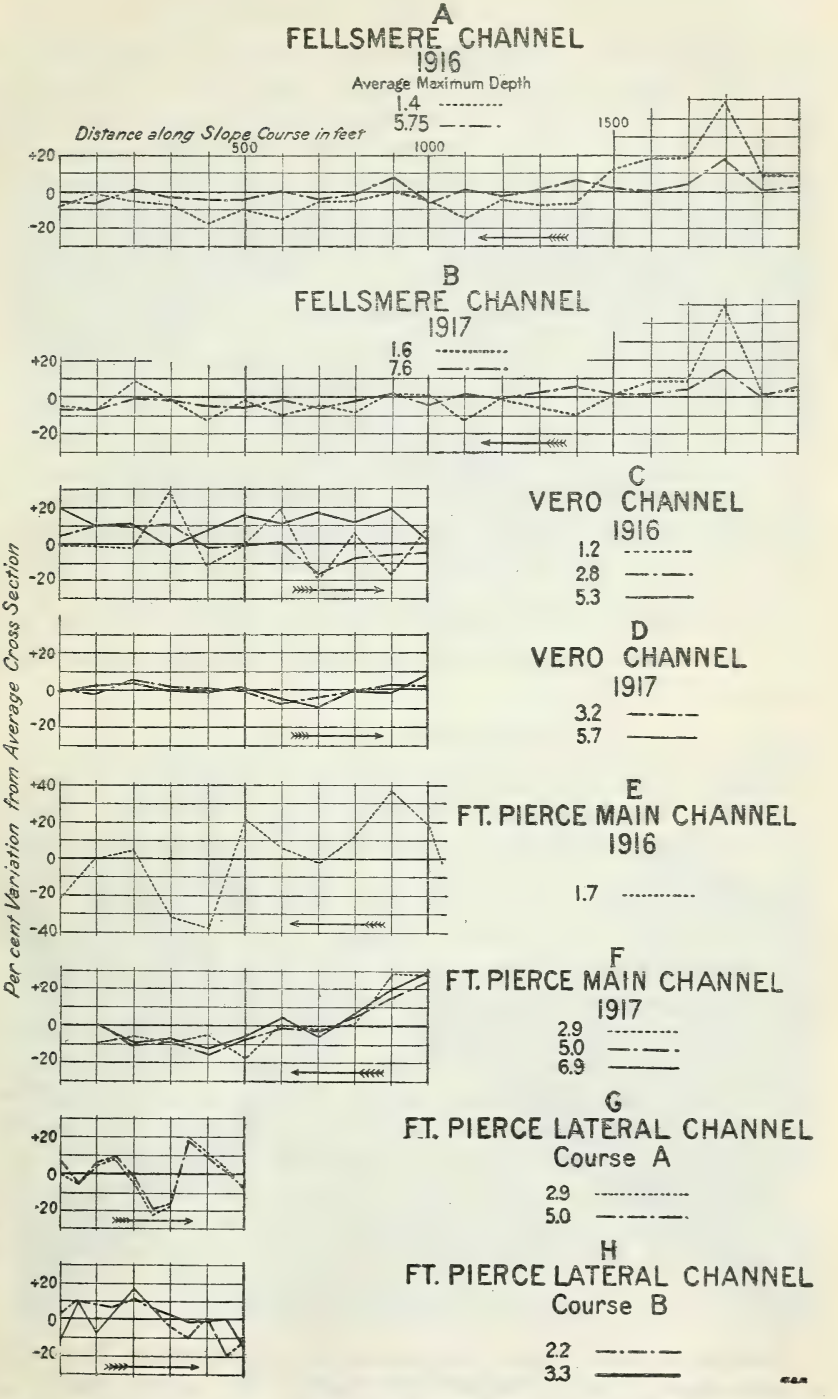


FIG. 12.—Graphs for experiments in Florida, showing per cent variation from average cross-sectional area for all cross sections along slope course.

### MAIN CHANNEL NEAR FELLSMERE.

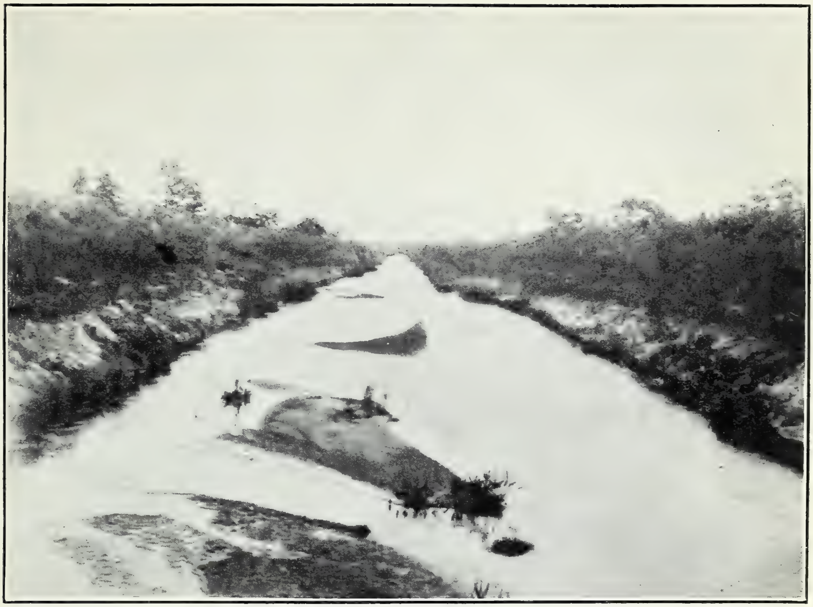
The slope course on this channel was straight and was 2,000 feet long. The gauging station was located about 100 feet below the downstream end of the slope course, which was about 3 miles north of Fellsmere. The gaugings were made from a footbridge about 10 feet upstream from the county highway bridge and supported by suspension brackets from the piling of that bridge. The channel was quite uniform in cross section, there being only one rather abrupt variation, which occurred near the upper end of the course (figs. 12 *A*, and 12 *B*). The bottom of the channel was broad and regular and quite evenly covered with sand. The side slopes were fairly regular and practically free from vegetation in the lower part of the channel, but rather irregular and covered with vegetation in the upper part (fig. 11 *A*, and Plate XVIII, fig. 2). With the exception of measurement 10, Table 6, for which the highest value of *n* was obtained, the measurements were made for stages almost wholly in the lower and better part of the channel. For the same part of the channel the values of *n* obtained during 1917 were somewhat lower than those obtained during 1916. This might be attributed to the fact that the cross section had become somewhat more uniform between the dates of the two sets of measurements, as appears from the graphs shown in figures 12 *A* and 12 *B*.

### MAIN CHANNEL NEAR VERO.

Gaugings of this channel were made from a suspension footbridge near Vero. The upper end of the slope course, which was 1,000 feet long, was located about 40 feet downstream from the gauging station. The bottom was sandy, and there were several flat, broad sand bars in the channel during low water (Plate XIX, fig. 1; and fig. 11 *B*). There was some vegetation in the channel, which can be seen in the view just referred to. The cross-sectional area of the channel was quite uniform except for the lowest measurements, Nos. 11 and 12 (see Table No. 6 and figs. 12 *C* and 12 *D*). The side slopes for the three low-stage measurements made during 1916 were fairly regular, but for the three higher stage measurements, Nos. 14, 15, and 19, made at about half-bankful stages, the slopes were quite rough and irregular, owing to the fact that large lumps of the bank had sloughed off. The values of *n* obtained indicate that the retardation to flow was much greater in the upper part than in the lower part of the channel, which was apparently due to the caving of the banks in the upper part of the channel.

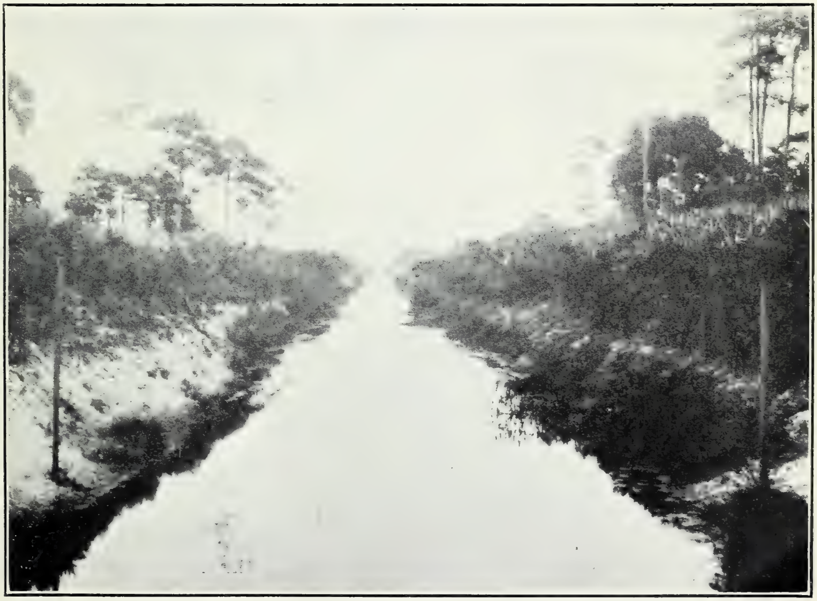
### MAIN CHANNEL NEAR FORT PIERCE.

Gaugings of this channel were made from a suspension footbridge located about 3 miles west of Fort Pierce. The upper end of the slope course, which was 1,032 feet long, was located about 25 feet



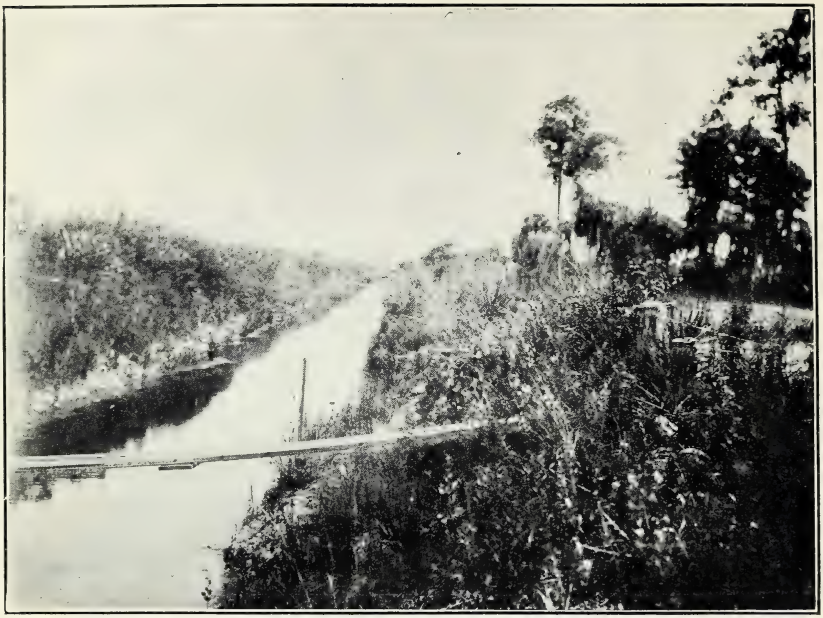
B. P. R.—D798

FIG. 1.—SLOPE COURSE OF MAIN DREDGED CHANNEL, NEAR VERO, FLA., 1917. (SEE TABLE NO. 6.)



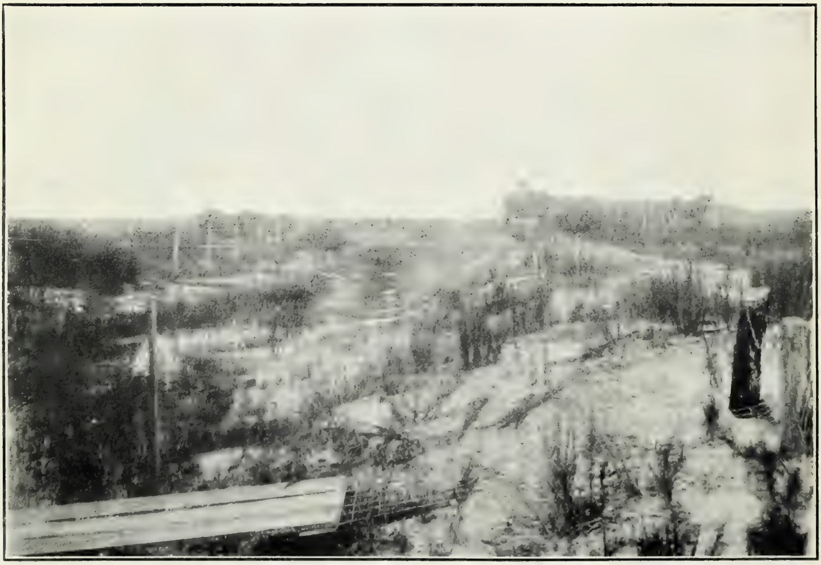
B. P. R.—D795

FIG. 2.—SLOPE COURSE OF MAIN DREDGED CHANNEL, NEAR FORT PIERCE, FLA., 1917. (SEE TABLE NO. 6.)



B. P. R.—D1353

FIG. 1.—SLOPE COURSE OF LATERAL DREDGED CHANNEL, NO. 2, COURSE A, NEAR FORT PIERCE, FLA., 1917. (SEE TABLE NO. 6.)



B. P. R.—D1354

FIG. 2.—SLOPE COURSE OF LATERAL DREDGED CHANNEL NO. 2, COURSE B, NEAR FORT PIERCE, FLA., 1917. (SEE TABLE NO. 6.)

downstream from the gauging station. At the time that the measurements were made during 1916 the cross section of the channel was fairly uniform, except for the lowest stage (Plate XIX, fig. 2; and figs. 11 *C* and 12 *E*). The side slopes were rather irregular. The soil in the bottom of the channel was largely clay, and on the side slopes a very hard clay. There were some water weeds in the bottom of the channel and a growth of grass and lilies near the water edge at low stage. As would be expected, a high value of *n* was obtained (Table 6) for the lowest stage, due to the vegetation and to the rough condition and abrupt variations in cross section. The other values were also rather high, due no doubt to the irregularities and vegetation in the channel.

The channel was cleaned out and deepened with a drag-line excavator after the 1916 measurements had been made. After this work had been done, values of *n* were again determined for the channel during 1917. The upstream end of the 1917 course was located 160 feet farther upstream than that of the 1916 course. The course was straight and was 900 feet long. The cross section of the channel was fairly uniform, there being no very abrupt variations (fig. 12 *F*), and was in rather good condition except for irregularities in the bottoms and some weeds that the excavating machine did not remove. Comparing the values of *n* obtained during 1917 with those for 1916, it is seen that much lower values were obtained after the channel was cleaned out and deepened.

### LATERAL DREDGED CHANNEL NO. 2, NEAR FORT PIERCE.

Values of *n* were determined for two courses of this lateral channel, course *A* being in good condition and course *B* in very poor condition. The gaugings were made from suspension foot bridges. A good idea as to the shape, condition, and uniformity of these channels can be obtained from Plate XX, and figures 11 *D*, 11 *E*, 12 *G*, and 12 *H*.

Course *A* was straight and was 503 feet long; it was located at a place where the channel passed through a ridge of hard clay. The side slopes of the channel were probably about as they were left by the excavating machine and showed no evidence of erosion or sloughing off. As may be seen from Plate XX, figure 1, there was some vegetation in the channel. The rather high values of *n* obtained for this channel were probably due to the presence of vegetation and to the abrupt variations in cross section.

Course *B* was straight and was 500 feet in length. This course was located in one of the so-called sand ponds. The soil is sandy and easily eroded. The banks have been washed in, and considerable material had been deposited in the channel. The cross section was very broad and shallow as compared with that for course *A* (fig. 11 *E*). There was considerable vegetation, covering the entire perimeter of the channel, as may be seen by referring to Plate XX, figure 2. The values of *n* obtained are very high, due no doubt principally to the presence of vegetation.

Unusual care was exercised in making the slope measurements and gaugings for both courses of channel. The slope for course *A* was very small and required precise measurements to secure reliable results.

### DISCUSSION OF FLORIDA EXPERIMENTS.

Owing to the fact that the slopes for channels in this section of the country are quite small, the velocities are necessarily low. As a result, the channels are subject to silting and to the rapid growth of vegetation. Unless channels in this section are to be carefully maintained, it can be seen from the results of the experiments as given in Table 6 that a comparatively high value of *n* should be used in their design.

## VARIATION OF *n* WITH STAGE IN CHANNEL.

The results of these experiments show that generally the value of *n* decreases as the stage in the channel increases. This was pointed out in an article in the Engineering News, February 24, 1916, by R. E. Horton, as being true for natural river channels and was attributed to the fact that:

> In determining the coefficients of roughness in natural river channels the entire cross section as determined by soundings is taken into account, whereas if the cross section is irregular there may be pockets or holes in the bed of the stream containing slack water at lower stages, so that the full area of section is not effective. Similarly at low stages of the stream there is likely to be more or less fall that is not effective as slope and that does not contribute to producing velocity.

While the above is also generally true for dredged channels, yet these experiments show a great many exceptions, one of which is that of Mud Creek, where the values of *n* obtained were practically the same for all stages in the channel, owing to the fact that there was no appreciable amount of ineffective slope or cross-section and practically no difference in the degree of roughness of the channel for different stages (see Plate III, fig. 1 and Table 1). Another exception which shows the very reverse of the general statement above is that of Bogue Phalia, where *n* increased for an increase of stage. This was due to the excellent condition of the lower part of the channel as compared with that of the upper part (see Plate V, fig. 1. and Table 2).

## APPLICATION OF RESULTS.

It is impossible to describe with absolute accuracy the conditions existing in a channel, such as degree of regularity, amount and nature of obstructions and vegetation, and uniformity of cross section.

Consequently it is impossible to formulate definite rules to govern one in choosing the proper value of *n* for any particular channel. It is believed that views, together with complete descriptions of channels for which the values of *n* have been determined, afford the best means of arriving at the proper value of *n* to employ for any particular channel. This applies especially to existing channels where it is desired to ascertain the capacity.

In order to determine the capacity of a proposed dredged channel it is necessary to assume anticipated conditions of channel. As is readily seen from the results of these experiments, values of *n* for dredged channels vary greatly, depending principally upon irregularities of side slopes and cross section due to erosion, caving banks, or faulty construction; upon obstructions and growth in the channel due to a lack of maintenance; and, under certain conditions, upon the effect of a lining of silt in the channel. In most cases where erosion takes place in a newly-constructed and well-finished dredged channel, the roughness coefficient increases, but the capacity of the channel as a rule also increases, since the enlarged cross section more than offsets the effect of the increased roughness coefficient. In some instances practically no difference in capacity in a newly-dredged channel may result due to erosion, after a certain amount of erosion has taken place, as was found to be the case for the experiments conducted at Trenton, Tenn. (see Table 3).

## CONCLUSIONS.

A careful study of the results of these experiments suggests the following conclusions:

(1) That a deposit of slick, slimy silt on the sides and bottom of a channel greatly reduces frictional resistance to flow (see results for Allen and Willow Creeks in Table 4).

(2) That the clearing of perennial growth from a channel will greatly increase its capacity (see results for Old Town Creek in Table 1).

(3) That the growth of grass and weeds in a channel during the summer greatly decreases its capacity (see results of experiments for North Carolina in Table 5).

(4) That the accumulation of drift, trees, logs and other obstructions in a channel greatly decreases its capacity (see results for South Forked Deer River Channel at Campbell's levee in Table 3).

(5) That after a certain amount of erosion has taken place in a channel, further erosion does not necessarily increase the roughness of the perimeter (see results for North Forked Deer River in Table 3).

(6) That the roughness coefficient *n* is appreciably higher for a roughly dredged channel than for a smoothly dredged one (see results for the South Forked Deer River at Jackson and Roberts, in Table 3).

(7) That ordinarily a dredged channel quickly deteriorates in hydraulic efficiency unless systematically maintained (see results for Old Town Creek in Table 1).

(8) That abrupt variations in cross section play an important part in reducing the hydraulic efficiency of a channel (compare figs. 2, 4, 6, 8, 10, and 12 with values of *n* in the tables).

(9) That generally, in designing a proposed dredged channel, a value of *n* of 0.030 should be used if the channel is to be smoothly dredged, and of 0.035 if roughly dredged. If the above values are used the channels should be carefully maintained, and if not to be so maintained a value of *n* should be selected in accordance with the worst anticipated conditions for the channel. However, if it is known that such conditions will obtain as were found for some of the channels in western Iowa, a somewhat lower value of *n* may be used, depending upon the anticipated conditions of the channel.

(10) That in computing the capacity of an existing channel the value of *n* chosen should whenever possible be based upon a comparison of the conditions in the existing channel with the conditions of channels for which values of *n* have been determined; such comparison being made, if not by actual inspection, at least with the aid of careful descriptions and views of the investigated channels.

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